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FASOMGHG Conceptual Structure, and Specification: Documentation

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SECTION 1 : BACKGROUND

1 CHAPTER 1: INTRODUCTION

This report describes the structure of the **F**orest and **A**gricultural **S**ector **O**ptimization **M**odel—**G**reen **H**ouse **G**as version (**FASOMGHG**), a dynamic, nonlinear programming model of the forest and agricultural sectors in the United States (US). The model simulates the allocation of land over time to competing activities in both the forest and agricultural sectors and the resultant consequences for the commodity markets supplied by these lands and, importantly for policy purposes underlying the development of this model, the net greenhouse gas (GHG) emissions. The model was developed to evaluate the welfare and market impacts of public policies that cause land transfers between the sectors and alterations of activities within the sectors. To date, FASOMGHG and its predecessor model FASOM have been used to examine the effects of GHG mitigation policy, climate change impacts, public timber harvest policy, federal farm program policy, biofuel prospects, and pulpwood production by agriculture. It can also aid in the appraisal of a wider range of forest and agricultural sector policies.

This report describes the structure of the FASOMGHG model in several levels of detail. Primary attention is devoted to the description of the model structure with alternative levels of detail:

McCarl note this needs to be updated to reflect full document when it is done it should correspond to the structure of the document

- Conceptual description of FASOMGHG model scope
- Economic description of FASOMGHG sectoral function
- Description of GHG modeling
- Detailed sectoral-specific description of modeling approach
- Operational description of approaches used to ensure tractability
- Description of model implementation in precise GAMS terms (see Appendix A)
- In addition we present material on the following subjects
- Origins and evolution of FASOMGHG
- Data specification approaches
- Broad categorizations of model output
- Policy applications to date and a review of findings
- Future plans

The report is divided into xxx text sections and four appendices. Following this Background section, the next section provides an overview of the major features of the model, such as the regional delineation and the basic structure of the forest, agricultural, and carbon accounting sectors in the model. The third text section describes the outputs of the FASOMGHG model, discusses how the model can be used to evaluate alternative policies for mitigating GHGs, and outlines potential future directions for the model. Appendix A contains additional detail on the scope of the agricultural model and Appendix B contains additional detail on the scope of the forest model. Appendix C provides a description of the computer program and data file structure for the FASOMGHG modeling system as a whole. Appendix D contains a detailed listing of the outputs of the model.

2 CHAPTER 2: ORIGINS OF AND NEW FEATURES IN FASOMGHG

FASOMGHG is an outgrowth of a number of previous lines of work:

- Agricultural Sector Modeling for environmental appraisal involving the Agricultural Sector Model (ASM) in its US Environmental Protection Agency (EPA), USDA Natural Resource Conservation Service (NRCS) and USDA Economic Research Service (ERS) supported applications to environmental and farm policy issues.
- Models of the US and Canadian forest sectors developed for the US Department of Agriculture (USDA) Forest Service's Resource Planning Act (RPA) Assessment process.
- USDA Forest Service efforts to examine the carbon sequestration consequences of changes in forest management using the FORCARB modeling system.
- Earlier EPA-supported efforts on the precursor to FASOMGHG - FASOM -that were motivated by the insight that the existing Forest Service Timber Assessment Market Model (TAMM) and ASM could neither simultaneously function together, nor adequately accommodate the dynamic and producer expectation issues raised by intersectoral land movement.
- Earlier EPA, USDA-Consortium for Agricultural Soils Mitigation of GHGs program (CASMGS), US Department of Energy (DOE)-- Carbon sequestration in terrestrial ecosystems program(CSiTE), and DOE--Office of Science- supported efforts to model agricultural GHG mitigation possibilities via a variety of sequestration, emission reduction, and biofuels-related possibilities.
- EPA-sponsored work to examine GHG mitigation "project-level" issues such as permanence, leakage, additionality, uncertainty, transactions costs, reversal and saturation.

Collectively all of these efforts came together in the form of a project to create FASOMGHG that involved participants from Texas A&M University, EPA, RTI International (RTI), Oregon State University, and USDA--Forest Service, along with important advice from numerous others. This project yielded a number of new features, an improved computer implementation and this document. Previously the only document that drew these components together was the PhD dissertation at Texas A&M by Lee (2002).

2.1 Brief review of predecessor projects

Below, we briefly review the main efforts and contributions of each of these lines of work to the overall FASOMGHG model.

2.1.1 ASM Modeling, Environmental and Farm Policy Analysis

One of the primary roots of FASOMGHG involves efforts by McCarl and colleagues to use sector modeling to appraise the economic and environmental implications of environmental and agricultural policy-related developments within the agricultural sector. This work began initially at Purdue University, was carried on later at Oregon State University, and eventually at Texas A&M University. The project originally began in the context of a cooperative agreement with USDA supporting a thesis by Baumes (1978). The model, hereafter called ASM, was subsequently improved for pesticide analysis by Burton (1982), as reported in Burton and Martin (1987). It was documented by Chattin et al. (1978), Adams et al. (1984), and Chang et al. (1992). Component documentation has appeared in McCarl and Spreen (1980), McCarl (1982), and Hamilton et al. (1985). In the late 1970s, ASM began to be used for environmental and resource analysis, first on biofuels (Tyner et al., 1979; Chattin, 1982; Hickenbotham, 1987), then on ozone (Hamilton, 1985; Adams et al., 1984), acid rain (Adams et al., 1993), soil conservation policy (Chang et al., 1994), global climate change (Adams et al., 1988, 1990, 1999, 2001; McCarl, 1999; Reilly et al., 2000, 2002), and climate change mitigation (Adams et al., 1993; McCarl and Schneider, 2001). It has also been used extensively for research evaluation (Tanyeri-Abur, 1990; Coble et al., 1992; Chang et al., 1991). A variant of the model has been adapted and used for about 20 years by the USDA Economic Research Service (House, 1987; Heimlich et al., 1998). ASM is incorporated into FASOMGHG, as will be discussed below.

The ASM model is a spatially disaggregated agricultural sector model representing the US in terms of 63 production regions and 10 market regions depicting trade with a number of foreign countries. ASM depicts production in an equilibrium year and is thus an intermediate run model giving implications for policy after it has been fully worked into the sector.

The FASOMGHG concept in part came out of the recognized limitations of an ASM study that was designed to examine issues regarding joint forestry and agricultural climate change mitigation (Adams et al., 1993). That study provided estimates of: (a) costs of sequestering carbon that took into account the increases in agricultural prices when agricultural crops were displaced by trees, and (b) impacts of different size programs on both the total and the distribution of the consumers' and producers' welfare in the agricultural sector. The study showed that harvesting the trees used to sequester carbon had the potential to greatly depress regional stumpage prices in the US.

That analysis incorporated forestry in terms of annualized equilibrium production budgets, containing a forestry representation with average (over time) wood product yields and also average costs. Such assumptions were required to reflect forestry production possibilities within the ASM static single-year equilibrium representation. An important limitation thereof is that there is no modeling of the dynamics of tree growth and timber harvesting decision making (i.e., trees were assumed to be harvested in a uniform, steady state fashion, and harvest age was not endogenous). Such assumptions do not adequately reflect a number of dynamic issues involved with land allocations to forestry versus agriculture. In turn, it was decided to develop a model that could depict such dynamics and FASOMGHG eventually arose.

2.1.2 Forest Service RPA Models

The basic structure of the forest sector was drawn from the family of models developed to support the US Forest Service's decennial RPA Timber Assessment process: TAMM (Timber Assessment Market Model; Adams and Haynes, 1980, 1996; Haynes, 2003), NAPAP (North American Pulp and Paper model; Ince 1994; Zhang et al 1993, 1996), ATLAS (Aggregate Timberland Assessment System; Mills and Kincaid, 1992), and AREACHANGE (Alig et al. 2003, 2004). Timber inventory data and estimates of current and future timber yields were taken in large part from the ATLAS input used for the 2000 RPA Timber Assessment (Haynes, 2003). The AREACHANGE models provide timberland area and forest type allocations to the ATLAS model. TAMM and NAPAP are "myopic" market projection models (they project ahead one period at a time) of the solid wood and fiber products sectors in the US and Canada. They treat markets at the wholesale product level (e.g., softwood lumber, softwood plywood, newsprint, linerboard, etc.) using econometric demand relations and a mix of econometric and activity analysis representations of supply. Log and timber demand relations are derived using fixed coefficients production representations. Timber supply functions (for sawtimber and pulpwood) are based on econometric analysis of historical harvest behavior by region and private owner class. Between annual market projections (supply-demand balance), both models update estimates of quasi-fixed capital stock (processing capacity) using either accelerator or Tobin's q approaches. Total harvest for all products is sent to ATLAS, which updates the timber inventory for removals and growth. ATLAS employs Johnson and Scheurman's (1977) "type II" format to represent the intertemporal development of timberland managed on an even-aged basis (using clearcuts) and their "type I" form for partially cut or selectively managed lands. In ATLAS, harvested lands are regenerated (grown) according to exogenous assumptions regarding the intensity of management and associated yield volume changes. The timberland base is adjusted for gains and losses projected over time by the AREACHANGE models, including afforestation of the area moving from agriculture into forestry.

The earliest version of the FASOM model considered only the log market. Secondary products (such as lumber or newsprint) were not explicitly represented, although the impacts of changes in the markets for those products were implicit in the shifts in log demand. Log demand relations were based on projections of the TAMM and NAPAP models. ATLAS provided the inventory and management input data but with a compressed set of management intensity options. The current FASOMGHG, in contrast, includes the full set of TAMM and NAPAP product, log, and stumpage markets. Product demand relations were extracted directly from the latest versions of TAMM and NAPAP, as were product supply relations for the solid wood products (such as lumber) and all product conversion coefficients for both solid wood and fiber commodities. Trade between the US and Canada in all major classes of wood products is endogenous and subject to the full array of potential trade barriers and exchange rates. Timber supply also uses nearly the full set of management intensity options available in ATLAS (e.g., for the South, seven planted pine management intensity classes directly from ATLAS), and the selection of management intensity is endogenous.

2.1.3 Forest Service FORCARB Modeling System

The forest carbon accounting component of FASOMGHG is largely derived from the Forestry Carbon (FORCARB) modeling system. FORCARB is an empirical model of forest carbon budgets simulated across regions, forest types, land classes, forest age classes, ownership groups, and carbon pools. The USDA Forest Service uses FORCARB, in conjunction with economic forest sector models (e.g., TAMM, NAPAP, ATLAS, and AREACHANGE) to estimate the total amount of carbon stored in US forests over time as part of the Forest Service's ongoing assessment of forest resources in general (i.e., pursuant to the RPA) and forest carbon sequestration potential in particular (Joyce 1995, Joyce and Birdsey 2000). Deriving FASOMGHG's forest carbon accounting structure from FORCARB ensures that forest carbon estimates from FASOMGHG can be analyzed and compared with ongoing efforts by the USDA Forest Service to estimate and project forest carbon estimates at the national level. It also enables FASOMGHG to be updated over time as the FORCARB system evolves to incorporate improved science.

FORCARB's in-forest carbon pool (trees, understory, litter, and soil) allocations were initially developed by researchers from the USDA Forest Service and colleagues in the mid-1990s (Plantinga and Birdsey, 1993; Birdsey and Heath, 1995; Birdsey, 1996). These model components have been modified in recent years via ongoing work by Smith et al. (2003) and Smith and Heath (2002). In addition, FORCARB tracks carbon stored in harvested wood products at and after the time of harvest. The wood product accounting component of

FORCARB was originally based on the work of Row and Phelps (1991) but has been modified based on the work of Skog and Nicholson (2000).

2.1.4 First Generation of FASOM

Development of the initial version of the FASOM model was motivated in part by the desire to project the carbon flux impacts of large areas of forest plantations resulting from hypothetical programs of afforestation on marginal agricultural lands. If trees on these afforested lands could be harvested for timber products, expected future prices in the forest sector would be affected, together with private owners' desires to hold timber stock and invest in the management of future timber stands. Future timber market changes would likely feed back to current decisions via price expectations. Similarly, the removal of large areas of agricultural land from production would presumably have some impact on farmers' cropping and land use decisions through changes in expected future agricultural prices. In their original forms, neither ASM nor TAMM included mechanisms for explaining intertemporal land management investments or the impacts of changing price expectations on investment behavior. And, since the models were independent, partial-equilibrium systems, there were no opportunities to reflect countervailing cross-sectoral price movements resulting from land shifts between the sectors.

The initial FASOM model addressed these limitations by linking a simple intertemporal model of the forest sector with a version of the ASM model in a dynamic framework, allowing some portion of the land base in each sector to be shifted to the alternative use. Land could transfer between sectors based on its marginal profitability in all alternative forest and agricultural uses over the time horizon of the model. Management investment decisions, including harvest timing in forestry, in both sectors were made endogenous, so they too would be based on the expected profitability of an additional dollar spent on expanding future output (both timber and carbon, if valued monetarily).

FASOM assumes intertemporal optimizing behavior by economic agents. The decision to continue growing a stand rather than harvesting it now is based on a comparison of the net present value of timber harvests from future periods and any GHG offsets obtained (not harvesting now) versus the net present value of harvesting now and replanting (or not replanting and shifting the land to agricultural use). Similarly, the afforestation decision would keep land in agriculture if it had a greater net present value there than in forestry, including any GHG monetary returns. This process establishes a land price equilibrium across the two sectors and, given the land base interaction, a link between contemporaneous commodity prices in the two sectors as well.

2.1.5 Agricultural Greenhouse Gas Mitigation Modeling—ASMGHG

While FASOM began work with GHG mitigation, it was basically limited in scope in coverage and response options. More specifically, FASOM only involved carbon stocks associated with trees, and wood products and to a lesser extent with land use change by incorporating an average level of carbon in forest and pasture land uses. Such an approach was not reflective of the spectrum of agricultural possibilities for GHG management. As a result, an EPA-funded project arose to widen the agricultural coverage of GHG management alternatives. This project manifested itself in the dissertation by Schneider (2000) and in the paper by McCarl and Schneider (2001) which expanded the ASM model as discussed earlier to include a detailed set of agricultural-related GHG management possibilities. That work expanded ASM to incorporate tillage change, land use exchange between pasture and crops, afforestation, fertilization alternatives, enteric fermentation, manure management, biofuels, fossil fuel use reduction, and rice land manipulation were included as well as a multigas framework. The resulting model was labeled ASMGHG. Again, the static equilibrium nature of ASMGHG and ASM omitted any modeling of the dynamic aspects of, particularly, the sequestration related strategies (forest and tillage) but also the dynamic market penetration restrictions caused by needed capital stock alterations to employ biofuels.

2.1.6 Original FASOMGHG by Lee

Given the dynamic and forest carbon sequestration coverage and the agricultural coverage in ASMGHG, it was decided to merge the agricultural alternatives into the FASOMGHG structure. This was manifest in the first version of FASOMGHG that was built in the context of Lee's dissertation (2002). In that work, the agricultural model was expanded to have all the GHG management alternatives in ASMGHG with the additional coverage of dynamics. In particular, features were introduced for agricultural tillage options, wherein sequestration gains were only assumed to occur for 20 years, which is a simplification of the true soil dynamics believed to occur. Features were also introduced for biofuels reflective of the need to adapt power plants to biomass fuel usage.

2.1.7 Project-Level GHG Mitigation Issues

While the work was proceeding on FASOMGHG, there was emerging interest stimulated by US GHG policy to begin to look at GHG mitigation potential at the project (site) level, rather than at the national level. GHG projects could, in principle, be part of a network of voluntary programs or limited scale GHG cap-and-trade across sectors. In that context, attention was devoted toward the issues of project transactions cost, economic incentives above and beyond cost differences, and possible reductions of project credits (discounts) for leakage of GHGs outside the project boundaries, possible impermanence of GHG benefits, non-additionality of project benefits, and uncertainty of project GHG outcomes.

2.2 New developments in this FASOMGHG version

Given the seven different endeavors above, an update of FASOMGHG was undertaken in 2004 which led to the version documented herein. The main revisions in that effort were

- updating of the biophysical and economic data,
- complete restructuring of the computer implementation
- expansion in the forest sector to include product as well as log markets,
- incorporation of wood products processing,
- expansion of the scope of agricultural sector GHG emission source and mitigation strategy coverage,
- improvement of the modeling of agricultural carbon sequestration dynamics,
- updating of the standing forest and wood product carbon accounting,
- addition of carbon accounting related to forest use of fossil fuels
- alteration of the model time step from 10 to five years, and
- improvement of model execution time characteristics.

SECTION 2 FOUNDATIONS

3 CHAPTER 3 CONCEPTUAL SCOPE OF FASOMGHG

Examining the role of forest and agricultural GHG mitigation in a dynamic setting requires an analytical framework that can depict the time path and GHG consequences of forestry and agricultural activity. FASOMGHG combines, for the US, component models of agricultural crop and livestock production, livestock feeding, agricultural processing, log production, forest processing, carbon sequestration, CO_2/non-CO_2 GHG gas emissions, wood product markets, agricultural markets, GHG payments, and land use to systematically capture the rich mix of biophysical and economic processes that will determine the technical, economic, and environmental implications of policy changes, climate change, and/or GHG mitigation opportunities.

Operationally, FASOMGHG is a multiperiod, intertemporal, price-endogenous, mathematical programming model depicting land transfers and other resource allocations between and within the agricultural and forest sectors in the US. The model solution portrays simultaneous market equilibrium over an extended time, typically 70 to 100 years on a five year time step basis. The results from FASOMGHG yield a dynamic simulation of prices, production, management, consumption, GHG effects, and other environmental and economic indicators within these two sectors, under the scenario depicted in the model data.

FASOMGHG's key endogenous variables include:

- commodity and factor prices,
- production, consumption, export and import quantities,
- land use allocations between sectors,
- management strategy adoption,
- resource use,
- economic welfare measures,
  - -- producer and consumer surplus,
  - -- transfer payments,
  - -- net welfare effects,
- environmental impact indicators,
  - -- GHG emission/absorption of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
  - -- surface, subsurface, and groundwater pollution for nitrogen, phosphorous, and soil erosion.

In the following sections we provide initial details on the overall scope of FASOMGHG in terms of resources, production, processing, and commodity flows; land coverage; geographic scope; market modeling; land allocation; GHG treatment; biofuels; use of a baseline; environmental indicators; dynamic scope; dynamic yield, cost, and demand updating.

3.1 Resources, Production, Processing, and Commodity Flows

The basic conceptual framework of FASOMGHG is presented below (**Figure 3-1**). Land, water, labor, and national inputs (fertilizer, capital, etc.) resources are used by forest, crop (including biofuels feedstock), and livestock production. In turn, the raw, primary commodities are produced and some move directly to markets while others move to processing making secondary commodities, direct feeding, or are blended into blended feeds. In turn, then the primary, secondary, biofuel feedstock, and blended feeds go to domestic demand, biofuels production, exports, or livestock feeding. In addition, imports enter the market place.

Figure 3-1. Overview of basic features modeled

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3.2 Commodity Scope

There are several major groupings of agricultural and forest commodities depending on the sector, whether they are raw, processed, mixed for livestock feed or biofuels relevant. These commodity groups are

- Raw crop, livestock, forestry, and biofuel feedstock primary commodities grown on the land (**Table 3-1**).
- Processed, secondary commodities made from the raw crop, livestock, and wood products (**Table 3-2**)
- Energy products made from biofuel feedstocks (also in **Table 3-2**)
- Blended feeds for livestock consumption (**Table 3-3**)

Agriculture and forestry commodities are quite frequently substitutable in demand. For example, sorghum is almost a perfect substitute for corn on a calorie for calorie basis in many uses and beet sugar is a perfect substitute for cane based sugar. Also, a number of feed grains are substitutes in terms of livestock feeding. FASOMGHG contains a set of processing activities which make secondary commodities. Secondary commodities are generally included in the model either to represent substitution or to depict demand for components of products. For example, processing possibilities for soybeans are included depicting soybeans being crushed into soybean meal and soybean oil because these secondary commodities frequently flow into different markets. Similar possibilities exist in the forest sector, for example, making paper from pulp logs or using logging residues, thereby including in the model a large degree of demand substitution.

Table 3-1. List of Raw, Primary Commodities

Crop Items	Units
Cotton	480-pound bales
Corn	Bushels
Soybeans	Bushels
SoftWhiteWheat	Bushels
HardRedWinterWheat	Bushels
DurhamWheat	Bushels
HardRedSpringWheat	Bushels
Sorghum	Hundred pounds (CWT)
Rice	CWT
Oats	Bushels
Barley	Bushels
Silage	US tons
Hay	US tons
Sugarcane	US tons
Sugarbeet	US tons
Potatoes	CWT
TomatoFrsh	Fresh tomatoes in 25-pound cartons
TomatoProc	Processing tomatoes in US tons
OrangeFrsh75box	Fresh market oranges in 75-pound boxes (California, Arizona)
OrangeFrsh90box	Fresh market oranges in 90-pound boxes (Florida)
OrangeFrsh85box	Fresh market oranges in 85-pound boxes (Texas)
OrangeProc75box	Processing market oranges in 75-pound boxes (California, Arizona)
OrangeProc90box	Processing market oranges in 90-pound boxes (Florida)
OrangeProc85box	Processing market oranges in 85-pound boxes (Texas)
GrpfrtFrsh67box	Fresh market grapefruit in 67-pound boxes (California, Arizona)
GrpfrtFrsh85box	Fresh market grapefruit in 85-pound boxes (Florida)
GrpfrtFrsh80box	Fresh market grapefruit in 80-pound boxes (Texas)
GrpfrtProc67box	Processing market grapefruit in 67-pound boxes (California, Arizona)
GrpfrtProc85box	Processing market grapefruit in 85-pound boxes (Florida)
GrpfrtProc80box	Processing market grapefruit in 80-pound boxes (Texas)
Livestock Items	**Units**
NonFedSla	100 pounds nonfed beef on the hoof
FeedlotBeefSlaughter	100 pounds fed beef on the hoof will be reported in 1,000s
CalfSlaugh	100 pounds of calf on hoof
CullBeefCo	100 pounds of cull beef cow on hoof
Milk	100 pounds of raw milk
CullDairyCows	100 pounds of cull dairy cow
HogsforSlaughter	100 pounds live weight
FeederPig	100 pounds live weight
CullSow	100 pounds live weight
LambSlaugh	100 pounds live weight
CullEwes	100 pounds live weight
Wool	Raw wool in pounds

SteerCalve	100 pounds of steer calves
HeifCalve	100 pounds of heifer calves

(continued)

Table 3-1. List of Raw, Primary Commodities (continued)

Livestock Items (continued)	Units
StockedCalf	100 pounds of calves after first stocker phase ready to feed
StockedHCalf	100 pounds of heifer calves after first stocker phase ready to feed
StockedSCalf	100 pounds of steer calves after first stocker phase ready to feed
DairyCalves	100 pounds of dairy calves
StockedYearling	100 pounds of yearlings after second stocker phase ready to feed
StockedHYearl	100 pounds of heifer yearlings after second stocker phase ready to feed
StockedSYearl	100 pounds of steer yearlings after second stocker phase ready to feed
HorsesandMules	Number of horses and mules in head
Eggs	Dozens of eggs at farm level
Broilers	100 pounds live weight
Turkeys	100 pounds live weight
Biofuel Feedstocks	
SwitchGrass	US tons
HybrdPoplar	US tons
Willow	US tons
Logs From Timber Harvest	
PVT_SWSLOG_WOODS	Softwood privately-produced sawlog in 1,000 cu. ft. in the woods
PVT_HWSLOG_WOODS	Hardwood privately-produced sawlog in 1,000 cu. ft. in the woods
PVT_SWPLOG_WOODS	Softwood privately-produced pulplog in 1,000 cu. ft. in the woods
PVT_HWPLOG_WOODS	Hardwood privately-produced pulplog in 1,000 cu. ft. in the woods
PVT_SWFLOG_WOODS	Softwood privately produced fuellog in 1,000 cu. ft. in the woods
PVT_HWFLOG_WOODS	Hardwood privately produced fuellog in 1,000 cu. ft. in the woods
PUB_SWSLOG_WOODS	Softwood publicly produced sawlog in 1,000 cu. ft. in the woods
PUB_HWSLOG_WOODS	Hardwood publicly produced sawlog in 1,000 cu. ft. in the woods
PUB_SWPLOG_WOODS	Softwood publicly produced pulplog in 1,000 cu. ft. in the woods
PUB_HWPLOG_WOODS	Hardwood publicly produced pulplog in 1,000 cu. ft. in the woods
PUB_SWFLOG_WOODS	Softwood publicly produced fuellog in 1,000 cu. ft. in the woods
PUB_HWFLOG_WOODS	Hardwood publicly produced fuellog in 1,000 cu. ft. in the woods
IMP_SWSLOG_WOODS	Imported softwood sawlog in the woods
IMP_HWSLOG_WOODS	Imported hardwood sawlog in the woods
IMP_SWPLOG_WOODS	Imported softwood pulplog in the woods
IMP_HWPLOG_WOODS	Imported hardwood pulplog in the woods
IMP_SWFLOG_WOODS	Imported softwood fuellog in the woods
IMP_HWFLOG_WOODS	Imported hardwood fuellog in the woods

Logs From Timber Harvest (continued)	Units
PVT_SWFLOG_MILL	Softwood privately produced fuellog in 1,000 cu. ft. delivered to the mill
PVT_HWFLOG_MILL	Hardwood privately produced fuellog in 1,000 cu. ft. delivered to the mill
PUB_SWSLOG_MILL	Softwood publicly produced sawlog in 1,000 cu. ft. delivered to the mill

PUB_HWSLOG_MILL	Hardwood publicly produced sawlog in 1,000 cu. ft. delivered to the mill
PUB_SWPLOG_MILL	Softwood publicly produced pulplog in 1,000 cu. ft. delivered to the mill
PUB_HWPLOG_MILL	Hardwood publicly produced pulplog in 1,000 cu. ft. delivered to the mill
PUB_SWFLOG_MILL	Softwood publicly produced fuellog in 1,000 cu. ft. delivered to the mill
PUB_HWFLOG_MILL	Hardwood publicly produced fuellog in 1,000 cu. ft. delivered to the mill
IMP_SWSLOG_MILL	Imported softwood sawlog delivered to the mill
IMP_HWSLOG_MILL	Imported hardwood sawlog delivered to the mill
IMP_SWPLOG_MILL	Imported softwood pulplog delivered to the mill
IMP_HWPLOG_MILL	Imported hardwood pulplog delivered to the mill
IMP_SWFLOG_MILL	Imported softwood fuellog delivered to the mill
IMP_HWFLOG_MILL	Imported hardwood fuellog delivered to the mill

Table 3-2. List of Processed, Secondary Commodities

Crop Items	Units
OrangeJuic	1,000 gallons at 42 brix
GrpfrtJuic	1,000 gallons at single strength equivalent
SoybeanMeal	US tons
SoybeanOil	Pounds of oil
HFCS	Gallons
Beverages	Gallons
Confection	100 pounds
Baking	100 pounds
Canning	100 pounds
RefSugar	US tons
GlutenFeed	100 pounds
Starch	100 pounds
CornOil	100 gallons
CornSyrup	Gallons
Dextrose	100 pounds
FrozenPot	100 pounds
DriedPot	100 pounds
ChipPot	100 pounds
CaneRefini	100 pounds
Livestock Items	
FedBeef	100 pounds fed beef carcass weight
NonFedBeef	100 pounds grass-fed beef carcass weight
Pork	100 pounds pork after dressing
Chicken	100 pounds on ready-to-cook basis
Turkey	100 pounds on ready-to-cook basis
WoolClean	Pounds of clean wool
FluidMilk	100 pounds
Cream	Pounds
SkimMilk	Pounds
EvapCondM	Pounds
NonFatDryM	Pounds
Butter	Pounds

AmCheese	Pounds
OtCheese	Pounds
CottageChe	Pounds
IceCream	Pounds
Biofuel Items	
Ethanol	Gallons
MktGasBlend	Gallons
SubGasBlend	Gallons
Tbtus	Trillion BTUs
Wood Products	
SLUM	Softwood lumber in millions board feet, lumber tally
SPLY	Softwood plywood in millions square feet, 3/8 inch
OSB	Oriented strand board (OSB) in millions square feet, 3/8 inch
HLUM	Hardwood lumber in millions board feet, lumber tally
HPLY	Hardwood plywood in millions square feet, 3/8 inch
SWPANEL	Softwood used in Non-OSB reconstituted panel
HWPANEL	Hardwood used in Non-OSB reconstituted panel
SWMISC	Softwood miscellaneous products in million cu. ft.
HWMISC	Hardwood miscellaneous products in million cu. ft.
SRESIDUES	Softwood residues in 1,000,000 cu. m.
HRESIDUES	Hardwood residues in 1,000,000 cu. m.
HWPULP	Hardwood pulp in 1,000,000 cu. m.
SWPULP	Softwood pulp in 1,000,000 cu. m.
AGRIFIBERLONG	Agrifiber (long fiber—endog.)
AGRIFIBERSHORT	Agrifiber (short fiber—endog.)
OLDNEWSPAPERS	Old newspapers in 1,000,000 metric tonnes
OLDCORRUGATED	Old corrugated in 1,000,000 metric tonnes
WASTEPAPER	Mixed wastepaper in 1,000,000 metric tonnes
PULPSUBSTITUTE	Pulp substitutes in 1,000,000 metric tonnes
HIGDEINKING	Hi-grade deinking in 1,000,000 metric tonnes
NEWSPRINT	Newsprint in 1,000,000 metric tonnes
UNCFREESHEET	Unc. free sheet in 1,000,000 metric tonnes
CFREESHEET	Coated free sheet in 1,000,000 metric tonnes
UNCROUNDWOOD	Unc. roundwood in 1,000,000 metric tonnes
CROUNDWOOD	Coated roundwood in 1,000,000 metric tonnes
TISSUE	Tissue and sanitary in 1,000,000 metric tonnes
SPECIALTYPKG	Specialty pkg. in 1,000,000 metric tonnes
KRAFTPKG	Kraft pkg. in 1,000,000 metric tonnes
LINERBOARD	Linerboard in 1,000,000 metric tonnes
CORRUGMED	Corrug. medium in 1000000 metric tonnes
SBLBOARD	Solid bl. board in 1000000 metric tonnes
RECBOARD	Recycled board in 1000000 metric tonnes
CONSTPAPER	Construc. paper and bd. in 1000000 metric tonnes
DISPULP	Dissolving pulp in 1000000 metric tonnes
SWKMPULP	Softwood kraft market pulp in 1000000 metric tonnes
HWKMPULP	Hardwood kraft market pulp in 1000000 metric tonnes
RECMPULP	Recycled market pulp in 1000000 metric tonnes
CTMPMPULP	Chemi-thermomechanical market pulp in 1000000 metric tonnes

Table 3-3. List of Blended feeds

Feed Items	
StockPro0	Protein feed for stockers in 100 lbs (cwt)
CatGrain0	Blend of grains for cattle in 100 lbs (cwt)
HighProtCa	Protein feed for cattle in 100 lbs (cwt)
CowGrain0	Blend of grains for cow calf operations in 100 lbs (cwt)
CowHiPro0	Protein feed for cow calf operations in 100 lbs (cwt)
FinGrain0	Blend of grains for pig finishing in 100 lbs (cwt)
FinProSwn0	Protein feed for pig finishing in 100 lbs (cwt)
FarGrain0	Blend of grains for farrowing operations in 100 lbs (cwt)
FarProSwn0	Protein feed for farrowing operations in 100 lbs (cwt)
FPGGrain0	Blend of grains for feeder pigs in 100 lbs (cwt)
FPGProSwn0	Protein feed for feeder pigs in 100 lbs (cwt)
DairyCon0	Blend of grains for dairy operations in 100 lbs (cwt)
BroilGrn0	Blend of grains for broilers in 100 lbs (cwt)
BroilPro0	Protein feed for broilers in 100 lbs (cwt)
TurkeyGrn0	Blend of grains for turkeys in 100 lbs (cwt)
TurkeyPro0	Protein feed for turkeys in 100 lbs (cwt)
EggGrain0	Blend of grains for eggs in 100 lbs (cwt)
EggPro0	Protein feed for eggs in 100 lbs (cwt)
SheepGrn0	Blend of grains for sheep in 100 lbs (cwt)
SheepPro0	Protein feed for sheep in 100 lbs (cwt)

3.3 Geographic Coverage

FASOMGHG covers forest and agricultural activity across the conterminous US, broken into 11 market regions meshed with 63 subregions for agricultural sector coverage. The 11 larger regions (see **Table 3-4 and figure 3-2**) are a consolidation of regional definitions that would otherwise differ if the forest and agricultural sectors were treated separately. The 11-region breakdown reflects the existence of regions for which there is agricultural activity but no forestry, and vice versa. In fact, forestry production occurs in nine of the larger 11 production regions, but agricultural sector activity can not be reasonably condensed to only these nine regions. For instance, the Northern Plains (NP) and Southwest (SW) regions reflect important differences in agricultural characteristics, but no forestry activity is included in either region. Likewise, there are important differences in the two Pacific Northwest regions (PNWW, PNWE) for forestry, but only the PNWE region is considered a significant producer of the agricultural commodities tracked in the model.

Figure 3-2. FASOMGHG Regions

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Agriculture is explicitly modeled in all 63 regions (**Table 3-5**) for the initial 20 years in the model run to provide maximum regional detail for the near to intermediate term. But for model size control purposes, agriculture is collapsed back to 11 regions after the first 20 years of the model run. Each of the 63 regions is uniquely mapped to the overall 11 regions as specified in **Table 3-64**. Note that when land moves between sectors in the model during periods when the 63 regions are active, that it moves on an 11 regions basis to and from the 63 regions in proportion to their initial land endowments.

Table 3-4. FASOMGHG 11 Region Definitions

Key	Region	States/Subregions
CB	Corn Belt	All regions in Illinois, Indiana, Iowa, Missouri, Ohio
NP	Northern Plains	Kansas, Nebraska, North Dakota, South Dakota
LS	Lake States	Michigan, Minnesota, Wisconsin
NE	Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
PNWE	Pacific Northwest-east side	Oregon and Washington, east of the Cascade mountain range
PNWW	Pacific Northwest-west side	Oregon and Washington, west of the Cascade mountain range
PSW	Pacific Southwest	All regions in California
RM	Rocky Mountains	Arizona, Colorado, Idaho, Montana, Eastern Oregon, Nevada, New Mexico, Utah, Eastern Washington, Wyoming
SC	South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Eastern Oklahoma, Tennessee, Eastern Texas (TxEast)
SE	Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
SW	Southwest	Western and Central Oklahoma, All of Texas but the Eastern Part -- Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, TexasTrans Pecos

Table 3-5 63 Regions Used in Agricultural Model

State	Substate Regions if Defined
Alabama	
Arizona	
Arkansas	
California	CaliforniaN, CaliforniaS
Colorado	
Connecticut	
Delaware	
Florida	

Georgia	
Idaho	
Illinois	IllinoisN, IllinoisS
Indiana	IndianaN IndianaS
Iowa	IowaW, IowaCent, IowaNE, IowaS
Kansas	
Kentucky	
Louisiana	
Maine	
Maryland	
Massachusetts	
Michigan	
Minnesota	
Mississippi	
Missouri	
Montana	
Nebraska	
Nevada	
NewHampshire	
NewJersey	
NewMexico	
NewYork	
NorthCarolina	
NorthDakota	
Ohio	OhioNW, OhioS, OhioNE
Oklahoma	
Oregon	
Pennsylvania	
RhodeIsland	
SouthCarolina	
SouthDakota	
Tennessee	
Texas	Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, TexasTrans Pecos, Texas East
Utah	
Vermont	
Virginia	
Washington	
WestVirginia	
Wisconsin	
Wyoming	

The pulp and paper sector employs a slightly different (more aggregated) set of US regions than the 11 used by the agriculture and solid wood sectors, following the regional definition in the North American Pulp and Paper (NAPAP) model (Zhang et al, Ince). These are defined in **Table 3-6**.

Table 3-6 US Regions Used in Pulp and Paper Industry

Key	Region	FASOMGHG Regions Included
NO	North	NC and NE
WEST	West	PNWW, PNWE, RM, and PSW
SC	South Central	SC
SE	South East	SE

Modeling international trade in agriculture entails use of some other regional definitions outside of the US In particular, 27 foreign trading regions are employed as mapped in Figure 3-3 and listed in table 3-7 below. The model's forest sector considers explicit endogenous trade only with Canada. The Canadian regions employed are defined in Table 3-8.

Table 3-7. Rest of World Production Trade Regions

Key	Region	Counties Included
1	WEST AFRICA	Dahomey, Angola, Benin, Cameroon, Canary Island, Ghana, Guinea, Ivory Coast, Liberia, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo, Burkina, South W. Africa, Zaire
2	NORTH AFRICA	Algeria, Libya, Morocco, Tunisia
3	EAST AFRICA	Botswana, Malawi, Kenya, Mozambique, South Africa, Tanzania, Uganda, Zambia, Zimbabwe, Rwanda, Madagascar, Swaziland, Lesotho, Burundi
4	EAST MED	Egypt, Israel, Lebanon, Syria.
5	RED SEA	Ethiopia, Somalia, Sudan, Yemen.
6	WEST ASIA	Afghanistan, Bangladesh, Nepal, Pakistan, Sri Lanka, India.
7	PERSIAN GULF	Iran, Iraq, Kuwait, Saudi Arabia, Bahrain, Oman, Un Arab Em
8	ADRIATIC	Cyprus, Greece, Turkey.
9	CHINA	China
10	SOUTHEAST ASIA	Hong Kong, Indonesia, Malaysia, New Zealand, Okinawa, Philippines, Singapore, Thailand, Vietnam, Fr Pac Is, So Pac Is, Other Pac Is.
11	JAPAN	Japan
12	SOUTH KOREA	South Korea
13	TAIWAN	Taiwan
14	EAST AMERICA	Belize, Brazil, Costa Rica, El Salvador, Curacao, Guatemala, Honduras, Nicaragua, Panama, Paraguay, Suriname, Uruguay, Venezuela, Fr Guiana.
15	CARRIBEAN	Lee Wind Is, Bahamas, Barbados, Dominican Rep, Fr West Ind, Haiti, Trinidad, Jamaica.
16	AUSTRALIA	Australia
17	N. CENTRAL EUROPE	Austria, Belgium, Germany, Netherlands, Switzerland
18	EAST BLOCK EUROPE	Bulgaria, Czechoslovak, Hungary, Poland, Romania, Yugoslavia
19	WESTERN EUROPE	Italy, Malta, Portugal, Spain, Others
20	ISLANDS	Iceland, Ireland, U.K.
21	SCANDINAVIA	Denmark, Finland, Norway, Sweden
22	CANADA	Canada
23	EAST MEXICO	Mexico
25	USSR	Former USSR
26	WEST AMERICA	Bolivia, Chile, Colombia, Ecuador, Peru

27	BRAZIL	Brazil
28	ARGENTINA	Argentina

Figure 3-3. Non-US agricultural Regions Defined in Model

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Table 3-8. Canadian Regions used in Forest Sector Trade Modeling.

	Key	Region	Provinces/countries
Regions used in Solidwood Sector	CBCC	Coastal British Columbia	Coastal British Columbia
	CINT	Interior Canada	Interior British Columbia, Alberta, Saskatchewan, and Manitoba
	CEST	Eastern Canada	The remainder of eastern Canada
Regions used in Pulp and Paper Sector	CWEST	Western Canada	CBCC and CINT
	CEAST	Eastern Canada	CEST

Both the solid wood and fiber products sectors can also trade with an "off-shore" region. This is the aggregate of all off-shore trading areas. Both imports and exports to this region are exogenous and pre-specified before a run, except for softwood lumber imports in the solid wood sector. In the later case, an aggregate imports supply relation is employed to represent trade flows from these non-Canadian regions.

3.4 Land base coverage

FASOMGHG covers all crop land, pasture land and private timberland in production throughout the conterminous ("lower 48") US. The remainder of this section describes the forest and agricultural land use definitions. The model's treatment of land allocation decisions is described further below in the chapter.

3.4.1 Agricultural land

On the agricultural side, FASOMGHG separates land into 63 regions (Table 3-4) initially and 11 in later periods (as discussed in the following section). Four major types of land are specified.

- **Crop land** is land suitable for crop production and is treated in four erodibility classes. The four erodibility classes are defined as follows. First, all crop land with USDA Land Capability Class III to VIII having a subclass of w (i.e., a wetness limitation for cropping) was grouped and labeled ***w3-8***. The remaining crop land was divided into three groups according to its erodibility index (ei). The ei is either RKLS/T from the Universal Soil

Loss Equation (USLE) (Wischmeier and Smith, 1978) or WEQ/T from the Wind Erosion Equation, depending on whether wind or water erosion gives the larger ei (T, the soil loss tolerance level, is the maximum allowable erosion for sustained crop production. The three ei groups are: ei < 8.0 in **loei**; 8.0 <= ei < 20.0 in ***mdei***; and ei ≥ 20.0 in ***svei***. NRI data coupled with USDA National Agricultural Statistics Service (NASS) data on county-level harvested acreage were used to specify land availability.

- **CRP land** that is specified as land enrolled in the Conservation Reserve Program based on signups as of 2000. Land in the CRP is marginal crop land retired from production and converted to vegetative cover, such as grass, trees, or woody vegetation for the purpose of conserving soil, improving water quality, enhancing wildlife habitat, or producing other environmental benefits.
- **Pasture land** is that suitable for livestock pasture.
- **AUM** grazing supply is divided into public and private grazing on the subregional level. Public grazing is available at a constant price while private grazing can be obtained by an upward-sloping supply schedule.

Agricultural land is allowed to move from the pasture land inventory into the crop land category and backwards. No more than 10 percent of the original endowment of pasture land can be converted to crop land on a regional over the whole time horizon. The conversion costs are set at the difference in the land rental rates between the alternative uses based on the assumed equilibration of land markets

Land is also tracked by crop tillage system and irrigated/dryland status and the duration of time it has been in such a system to allow tracking of sequestered soil carbon and approach to a new soil carbon equilibrium after tillage change.

3.4.2 Forestland

Timberland refers to productive forestlands able to generate at least 20 cubic feet of live growing stock per acre per year and which are not reserved for uses other than timber production (e.g., wilderness use). Lands under forest cover that do not produce at least 20 cubic feet per year, called unproductive forestland, and timberland that is reserved for other uses are not considered part of the US timber base and are therefore not tracked by the model. In FASOMGHG, endogenous land use modeling is only done for privately held parcels, not publicly owned or managed timberlands. The only public land treatment is accounting for the quantity of timber cut from all US forestland owned and operated by any public entity as an exogenous assumption, and simulation of timber inventory levels for National Forest timberlands using exogenous timber harvest levels. In other words, the amount of public land in forests is not assumed to adjust to market conditions; rather, it is set by government administrative decree.

Private land in forestry is also treated according to its quality, and transferability between forestry and agricultural use. FASOMGHG includes three different site classes, as measures of forest productivity:

- HIGH—high site productivity group (as defined in ATLAS),
- MEDIUM—medium site productivity group; and
- LOW—low site productivity group.

The site groups were defined based on ATLAS inputs from the 1993 RPA Update (Haynes et al., 1995). Yields vary markedly by site groups.

FASOMGHG also tracks land ownership including two private forest owner groups: forest industry (FI) and nonindustrial private forests (NIPF). The traditional definitions are used for these ownership groups, wherein industrial timberland owners are those that possess processing capacity for the timber, and NIPF owners do not.

In terms of forest land, FASOMGHG tracks land in terms of the type of timber management, the species on the land, and the stand age. There are 18 different possible management intensity classes depending on whether thinning, partially cutting, passive management, some other management methods are used. The full spectrum of these management intensity classes is defined later in the forestry data chapter. There are also 25 different forest species types, which vary by region (e.g., Douglas fir and other species types in the West and planted pine, natural pine, and various hardwood types in the South), as defined in the forest data section below. In terms of stand age initially forest data and have forested stands are explicitly accounted for in five year cohorts in terms of the years it has occupied the land (not necessarily the tree age if older seedlings are transplanted in as is common in the South), with the age class scheme covering 0-4, 5-9, 10-14, etc., up to 95-00 and 100 plus years.

3.5 Production Modeling

The production component includes agricultural crop and livestock operations, as well as private non-industrial and industrial forestry operations. Harvests from public forest lands are included in the model, but are treated as exogenously determined by the government. Production is modeled for the raw primary products listed in Table 3-6, except those imported. Production activity is depicted over a 70 to100-year period, with explicit accounting on a five year basis.

3.5.1 Agricultural and Biofuel feedstock Production

Operationally, FASOMGHG contains an agricultural production model for the above listed primary crop, livestock, and biofuels feedstock commodities in each of the included five year periods. Agricultural crop, biofuels and livestock production competes for land, labor, AUM grazing, and irrigation water at the 63 or 11-region level, depending on the regional level for the included five year implementations (63 regions for the first 20 years and 11 thereafter). The cost of these and other inputs are included in the budgets for regional production variables.

Budgets are present for the crop and biofuel feedstocks listed in Table 3-9. For each crop, production budgets are differentiated by region, tillage choice, fertilization alternative (three choices: 70, 85 and 100% of base levels), irrigated or dryland and crop land type (four as discussed in land use section above). Thousands of cropping production possibilities (budgets) represent agricultural production in each five year period. Biofuel feedstock possibilities are similar, except that irrigation is not an option.

Table 3-9. Crops in FASOMGHG

Crop	Units
Cotton	Cotton in 1,000 acres
Corn	Corn in 1,000 acres
Soybeans	Soybeans in 1000 acres
DurhamWheat	Durham Wheat in 1000 acres
HardRedSpringWheat	Hard Red Spring Wheat in 1000 acres
HardRedWinterWheat	Hard Red Winter Wheat in 1000 acres
SoftWhiteWheat	Soft White Wheat in 1000 acres
Sorghum	Sorghum in 1000 acres
Rice	Rice in 1000 acres
Oats	Oats in 1000 acres
Barley	Barley in 1000 acres
Silage	Silage in 1000 acres
Hay	Other Hay in 1000 acres
Alfalfa	Alfalfa Hay in 1000 acres
Sugarcane	Sugar Cane in 1000 acres
Sugarbeet	Sugar Beets in 1000 acres
Potatoes	Potatoes in 1000 acres
Fallow	Fallow land in 1000 acres
TomatoFrsh	Tomatoes for fresh market in 1000 acres
TomatoProc	Tomatoes for processed market in 1000 acres
OrangeFrsh	Oranges for fresh market in 1000 acres
OrangeProc	Oranges for processed market in 1000 acres
GrpFrtFrsh	Grapefruit for fresh market in 1000 acres
GrpFrtProc	Grapefruit for fresh market in 1000 acres
SwitchGrass	Switch grass for biofuels
HybrdPoplar	Hybrid Poplar for biofuels

Willow	Willow for biofuels

Livestock production considers production of the animal types in Table 3-10. Livestock budgets are defined by region, animal type, enteric fermentation management alternative, manure management alternative, and feeding alternative. Hundreds of livestock production possibilities (budgets) represent agricultural production in each five year period.

Table 3-10. Types of Animals in FASOMGHG

Sheep	Production of sheep in head
CowCalf	Cow calf production per cow
FeedlotBeefYearlings	Beef feeding of yearlings in units of head
FeedlotBeefCalves	Beef feeding of calves in units of head
Dairy	Dairy Production in units of cows
HogFarrowtofinish	Hog farrowing to finishing in unit of head of finished hog
FeederPigProduction	Feeder pig production in unit number of sows
PigFinishing	Pig finishing in unit of finished hog
HorsesandMule	Other livestock mainly horses in number of head
SteerCalfStocker	Stocker operation with steer calves in number of calves
HeiferCalfStocker	Stocker operation with heifer calves in number of calves
SteerYearlingStocker	Stocker operation with steer yearlings in number of yearlings
HeiferYearlingStocker	Stocker operation with heifer yearlings in number of yearlings
produceTurkey	Turkeys produced in units of birds reported in thousands
Broiler	Broilers produced in units of birds reported in thousands
Egg	Egg production on a 1 laying hen basis

Supply curves for agricultural products, and GHG mitigation are implicitly generated within the system as the outcome of competitive market forces and market adjustments. This is in contrast to supply curves that are estimated from observed, historical data. This approach is useful in part because FASOMGHG could be employed to analyze conditions which fall well outside the range of historical observation (such as large scale tree-planting programs).

3.5.2 Forest Production

The forest production component of FASOMGHG depicts the use of existing private timberland[1] as well as the reforestation decision on harvested land. Timberland is differentiated

[1] Timberland is the subset of forestland that is capable of producing at least 20 cubic feet per acre per year of industrial wood at culmination of mean annual increment and is not withdrawn from timber harvesting or related timbering activities.

by region, the age cohort of trees,[1] ownership class, cover type, site condition, management regime, and suitability of the land for agricultural use. These forestry activities produce the log products listed in Table 3-6 (primary product table). Decisions pertaining to timber management investment are endogenous. Actions on the inventory are depicted in a framework that allows timberland owners to institute management activities that alter the inventory consistent with maximizing the net present value of the returns from the activities. The timberland decisions for existing stands involve selecting the harvest age. Lands that are harvested and subsequently reforested or lands that are converted from agriculture to forestry (afforested) introduce decisions involving the choice of species type, management type, and future harvest age.

3.6 Land Allocation

Underlying the commodity production described above and the GHG consequences thereof is the decision by landowners on how much, where, and when to allocate land across the two sectors. Endogenous land allocation across sectors sets FASOMGHG (and FASOM) apart from other forest and agricultural sector models of the US The conceptual foundation for land allocation is described below.

3.6.1 Scope for Land exchanges between sectors

The basic structure of the land exchanges is portrayed in **Figure 3-1**. In terms of transferability between agriculture and forestry there are five land suitability classes:

- FORONLY—includes timberland acres which can not be converted to agricultural uses;
- FORCROP—includes acres which begin in timberland and which can be converted to crop land;
- FORPAST—includes acres which begin in timberland and which can be converted to pasture land;
- CROPFOR—includes acres which begin in crop and which can be converted to timberland; and
- PASTFOR—includes acres which begin in pasture and which can be converted to timberland.

Land can flow between the agricultural and forestry sectors or vice versa in the FORCROP, FORPAST, CROPFOR, and PASTFOR land suitability categories. Land movements in forestry are only allowed in the NIPF owner category. When land transfers from

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[1] Timberlands are grouped in 21 five year cohorts, 0 to 4 years, 5 to 9,…, up to 100+ years. Harvesting is assumed to occur at the midyear of the cohort.

forestry to agriculture, it requires an investment to clear stumps, level, and otherwise prepare the land for planting. Land moving from agriculture to forestry must be planted to forest and land movement from forestry occurs only upon timber harvest. Agricultural land can move to other uses during any of the five year model periods, but when afforested it begins in the youngest age cohort of timberland.

When land moves from or to agricultural crops, it involves the high quality forest site class and moves in the erosion classes proportional to their existence in the region. Movements involving pasture come from the medium quality forest site class. Movements from pasture to timberland are also proportional across all erodibility classes.

Land also moves into non-agricultural and non-forestry uses (e.g., shopping centers, housing, and other developed and infrastructural uses) based on exogenous estimates by Alig et al. (2004) and in proportion to the initial land endowments at exogenously specified rates. Land movement from forestry again occurs only upon timber harvest.

Figure 3-1. Characterization of land movements

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DROP (TAMM based) FROM FIGURE

3.6.2 Nature of Land Supply

In FASOMGHG, the initial land endowment is fixed. However, since land is allowed to move between forest and agriculture, agricultural production faces an endogenous excess land supply equation from forestry. Forestry production, in turn, faces an endogenous excess land supply equation from agriculture. Conservation Reserve Program (CRP) land is assumed to be permanently fixed at the initial levels, unless manipulated by a policy scenario. Animal Unit Month (AUM) grazing land supply is specified using an upward-sloping supply function reflecting the availability of more remote and less suitable lands.

3.7 Non-Land Factor Modeling

In addition to land, FASOMGHG depicts factor supply of water, labor, AUM grazing, other agricultural inputs in agriculture, as well as non-wood inputs in the forest sector.

On the agricultural side, water and labor are available in each of the 11 or 63 agricultural regions (recall agricultural regional definitions will generally aggregate from 63 to 11 regions after the first 20 years of model runs). Labor is available on an 11 region basis. Supply curves for all three items have a fixed price component and an upward sloping component, representing rising marginal costs of higher supply quantities. For water, the fixed price is available to a maximum quantity of federally provided agricultural water, while pumped water has an upward sloping supply curve and is subject to maximum availability. For AUMs, the fixed price is available to a maximum quantity of public grazing, while private grazing has an upward sloping supply curve and is subject to maximum availability. For agricultural labor, the fixed price is available to a maximum quantity of federally provided agricultural water, while pumped water has an upward sloping supply curve and is subject to maximum availability. Other inputs are assumed to be infinitely available at a fixed price (i.e., the agricultural sector is a price taker in these markets).

On the forestry side, non-wood inputs are available on an upward sloping basis and include hauling, harvesting, and product processing costs. Other forest costs are assumed to be infinitely available at a fixed price.

3.8 Product Processing Modeling

As indicated above, raw product commodities are converted on both the agricultural and forestry sides into processed products. The processing activities in the model generally reflect a somewhat simplified view of the resources used in processing. They largely contain primary commodity usage, secondary commodity yield, and a level of cost. Thus, for example, in soybean crushing the processing activity uses one unit of soybeans and generates a given number of pounds of soybean meal and tons of soybean oil at a specified cost. The cost on the agricultural side is usually the observed price differential between the value of the outputs and the value of the inputs according to USDA Agricultural statistics (1990-2002). On the forestry side, the non-wood input supply curve provides the cost of processing wood.

Wood product processing is always regionalized with different data in the 9 forest production regions and the Canadian regions. Agricultural processing is regionalized for biofuels, soybean crushing, wet milling, electricity generation from willow, switch grass and poplar and ethanol production from corn, willow, switch grass and poplar as will be discussed below. For the remaining agricultural items listed in Table 3-11, below the processing is done at a national level as discussed below.

Table 3-11. Agricultural Processing Alternatives

Processing activity code	Brief description
BroilChick	Convert broilers to chicken meat
ButterPow	Make butter and non fat dry milk powder
CaneRefine	Convert raw cane sugar to refined sugar
Chip-Pot	Make potato chips
ClCowSla	Convert cull cow to non fed slaughter
CleanWool	Convert wool to clean wool
Cottage	Make cottage cheese
DClfToBeef	Convert cull dairy calf to non fed slaughter
DCowSla	Convert cull dairy cow to non fed slaughter
DeHydr-Pot	Make dehydrated potatoes
EvapoMilk	Make evaporated milk
FluidMlk1	Make 2 percent milk
FluidMlk2	Make skim milk
Frozen-Pot	Make frozen potatoes
FSlatofBe	Convert fed animal to fed slaughter
Gluttosbm	Substitute gluten feed for soybean meal
HeiferYearlingSlaughter	Slaughter a heifer yearling
HogToPork	Convert finished hogs to pork
HybridpoplarToElec	Make hybrid poplar into electricity
HybridpoplarToEthanol	Make hybrid poplar into ethanol
IceCream1	Make ice cream alternative 1
IceCream2	Make ice cream alternative 2
JuiceGrpft	Make grapefruit juice
JuiceOrang	Make orange juice
makeAmCheese	Make American cheese
makeBaking	Make sweetened baked goods
makeBeverages	Make sweetened beverages
makeCanning	Make sweetened canned goods
makeConfection	Make sweetened confectionaries
makeCSyrup	Make corn syrup
makeEthanol	Make ethanol
makeHFCS	Make high fructose corn syrup
makeMktGasBlend	Make unsubsidized liquid fuel blending gasoline & ethanol
makeOtCheese	Make other cheese
makeSubGasBlend	Make subsidized liquid fuel blending gasoline & ethanol
makeDextrose	Make dextrose
NFSlatonF	Convert non fed animal to non fed slaughter
RefSugar1	Convert sugar cane to raw cane sugar
RefSugar2	Convert sugar beets to refined sugar
SowToPork	Convert cull sow to pork
SoyCrush1	Crush soybeans
StockHeiferCalftoFeed	Move stocked heifer calf into feedlot
StockHeiferYearlingtoFeed	Move stocked heifer yearling into feedlot

StockSteerCalftoFeed	Move stocked steer calf into feedlot
StockSteerYearlingtoFeed	Move stocked steer yearling into feedlot
SteerYearlingSlaughter	Slaughter a steer yearling
TurkeyProc	Convert live turkeys to turkey meat
SwitchgrassToElec	Make switchgrass into electricity
SwitchgrassToEthanol	Make switchgrass into ethanol
WetMill	Wet mill corn
WillowToElec	Make willow into electricity
WillowToEthanol	Make willow into ethanol

3.9 Market Modeling

xxxRecommendation: This section could really benefit from a table that shows which products are represented by different supply regions in the US, whether demand is regional or national, whether international trade is included and, if so, how is international trade tracked regionally outside of the US

The model solves by ensuring that each affected market is in equilibrium, wherein the quantity supplied equals the quantity demanded. This involves a mixture of implicit and explicit demand and supply curves in each five year period. Generally these involve

- regional product supply,
- national raw product demand,
- regional or national processed commodity demand,
- regional or national supply of processed commodities,
- regional or national (depending on commodity) export demand
- regional or national (depending on commodity) import supply,
- regional feed supply and demand,
- regional direct livestock demand,
- interregional transport perfectly elastic supply,
- international transport perfectly elastic supply and
- country-specific excess demand and supply of rice, sorghum, corn, soybeans and the 5 types of wheat

On the forestry side, all commodities are produced regionally and are then transported to meet a national demand at a fixed transport cost. Canadian sawlog production is based on regional log supply curves and must be processed within the region of origin. The only exception is a small volume of log exports from Canada to the US and other regions which are treated as exogenous export flows from Canada and an exogenous import flow to the US. Endogenous export flows from Canada include softwood lumber, OSB and all fiber products to the US. US exports to Canada are exogenous.

On the agricultural side, corn, soybeans, four types of wheat, rice, and sorghum are modeled with US regional features and explicit demand in 27 foreign regions. The processed commodities of soybean meal, gluten feed, starch, and all livestock feeds are manufactured and used on a FASOMGHG 11 market region basis but go into national demand and international trade.

3.10 GHG Treatment

FASOMGHG quantifies the stocks of GHGs emitted from and sequestered by agriculture and forestry, plus the stock on lands in the model that are converted to nonagricultural, nonforest developed usages. In addition, the model tracks GHG emission reductions in other sectors caused by mitigation actions in the forest and agricultural sectors -- for example, reduced GHG emissions from fossil fuel use in the energy sector due to supply of renewable biofuel feedstocks from agriculture.

As indicated above, GHGs tracked by the model include carbon dioxide (CO_2) -- sometimes expressed in carbon (C) equivalent, methane (CH_4), and nitrous oxide (N_2O). The GHG accounting spans across both sectors and biofuels. A list of all the categories in the GHG accounting appears in Table 3-12 below.

Table 3-12. List of All GHG Accounts in FASOMGHG

Account Name	Brief description
Forest_ContinueSoil	Carbon in forest soil of forests that remain forests
Forest_AfforestSoil	Carbon in forest soil of afforested forests
Forest_ContinueLitUnd	Carbon in litter and understory of forests that remain forests
Forest_AfforestLitUnd	Carbon in litter and understory of afforested forests
Forest_ContinueTree	Carbon in trees of forests that remain forests
Forest_AfforestTree	Carbon in trees of afforested forests
Forest_USProduct	Carbon in US consumed and produced wood products
Forest_CANProduct	Carbon in US consumed but Canadian produced wood products
Forest_USExport	Carbon in US produced but exported wood products
Forest_USImport	Carbon in US consumed but imported from non Canadian source
Forest_USFuelWood	Carbon in US consumed fuelwood
Forest_USFuelResidue	Carbon in US residue that is burned
Carbon_For_Fuel	Carbon emissions from forest use of fossil fuel
Dev_ForestLand	Carbon on forest land after it moved into developed use
Dev_AgLand	Carbon on agricultural land after it moved into developed use

AgSoil_Continue_Till	Carbon on land moving continuing initial tillage
Soil_AgToForest	Carbon deductions when moving land between crops and forest
AgSoil_Change_Till	Carbon on land changing intensity of tillage
AgSoil_ToFromPast	Carbon on land changing between pasture and crop
AgSoil_Pasture	Carbon on land remaining as pasture
AgSoil_IdlePasture	Carbon on land that is idle pasture land
Carbon_SoilCmix	Soil carbon differences due to crop
Carbon_AgFuel	Carbon emissions from ag use of fossil fuel
Carbon_Dryg	Carbon emissions from grain drying
Carbon_Fert	Carbon emissions from fertilizer production
Carbon_Pest	Carbon emissions from pesticide production
Carbon_Irrg	Carbon emissions from irrigation water pumping
Carbon_Ethl	Carbon emission savings from ethanol production
Carbon_CEth	Carbon emission savings from cellulosic ethanol production
Carbon_BioFuel	Carbon emission savings from biofuel production
Methane_Liquidmanagement	Methane from Emission savings from improved manure technologies
Methane_EntericFerment	Methane from Enteric Fermentation
Methane_Manure	Methane from Manure Management
Methane_RiceCult	Methane from Rice Cultivation
Methane_AgResid_Burn	Methane from Agricultural Residue Burning
Methane_BioFuel	Methane emissions of biomass power plants below coal power plants
Methane_Ethl	Methane emission savings from Corn ethanol processing
Methane_CEth	Methane emission savings from cellulosic ethanol processing
NitrousOxide_Manure	Livestock Manure Practices
NitrousOxide_Biofuel	Nitrous oxide emissions of biomass power plants over coal power plants
NitrousOxide_Ethl	Nitrous oxide emission savings from Corn ethanol processing
NitrousOxide_CEth	Nitrous oxide emissions from cellulosic ethanol processing
NitrousOxide_Fert	N Fert Application Practices under Managed Soil Categories under AgSoilMgmt
NitrousOxide_Sludge	Emissions from sewage sludge used as crop fertilizer
NitrousOxide_Nfixing	Emissions from N fixing crops
NitrousOxide_CropResid	Emissions from Crop residue retention
NitrousOxide_Histosoil	Emissions from Temperate histosoil area
NitrousOxide_Volat	Indirect soils volatilization
NitrousOxide_Leach	Indirect soils Leaching Runoff
NitrousOxide_AgResid_Burn	Agricultural Residue Burning

3.10.1 Forest GHG Accounts

Forest GHG accounting includes carbon sequestered, carbon emitted, and fossil fuel-related carbon emissions offset. Sequestration accounting encompasses carbon in standing trees, forest soils, forest understories and floors including woody debris, and wood products both in use and in landfills. The sequestration accounting involves both increases and reductions in stocks, with increases entered when land moves into the forest uses, trees grow, and products are placed in long-lasting uses or landfills. Reductions arise when timber stands are harvested, land is migrated to agriculture or development, and products decay in their current uses.

Forest-related emissions accounting counts the GHGs emitted when fossil fuels are combusted in forest production. Forest-related GHG offset accounting is done for the estimated amount of fossil fuel fuels that are saved when wood products are combusted in place of fossil fuels, particularly when milling residues are burned. In addition, wood products may be used as a biofuel to offset fossil fuel emissions, as discussed in the biofuels section below.

Forest carbon accounts also include the carbon content of products imported into the US or exported out of the US. In particular there is accounting for products:

- Processed in and coming from Canada,
- Imported from other countries, and
- Exported to other countries.

These categories may or may not be included in an incentive scheme for GHG mitigation, as they will generally be accounted for elsewhere. Nonetheless, the accounts are included in the model in case they are needed for policy analysis.

More detail on the data and models used to estimate forest carbon stock accumulation is included in Chapter 8.

3.10.2 Agricultural GHG Accounts

On the agricultural side, the main features of the GHG accounting are those listed in table 3-13 below. Again, there is coverage of the emissions, sequestration, and offsets. Agricultural emissions arise from crop and livestock production, principally from:

- fossil fuel use,
- nitrogen fertilization usage,
- rice production,
- enteric fermentation, and
- manure management and other categories that are not fully listed in table but are given in the previous table.

Agricultural sequestration involves the amount of carbon sequestered in agricultural soils, due principally to choice of tillage, and irrigation along with changes to crop mix choice. Sequestration is also considered in terms of grasslands versus crop land or mixed usage, where crop land can be moved to pasture use or vice versa. The sequestration accounting can yield either positive or negative quantities, depending upon the direction of tillage (conventional, low, or zero tillage) and irrigation choices, along with pasture land (grassland)/crop land land conversions. The sequestration accounting will also have a negative term when land moves out of agriculture into forestry or developed use. Although in the case of forestry, the loss in agricultural carbon will typically be more than offset by gains in forest carbon.

Table 3-13. Mitigation strategies in FASOMGHG

		GHG affected		
Mitigation strategy	Strategy Nature	CO_2	CH_4	N_2O
Biofuel production	Offset	X	X	X
Crop mix alteration	Emission, Sequestration	X		X
Rice acreage reduction	Emission		X	
Crop fertilizer rate reduction	Emission	X		X
Other crop input alteration	Emission	X		
Crop tillage alteration	Sequestration	X		
Grassland conversion	Sequestration	X		
Irrigated /dry land conversion	Emission	X		X
Livestock management	Emission		X	
Livestock herd size alteration	Emission		X	X
Livestock system change	Emission		X	X
Liquid manure management	Emission		X	X

3.10.3 Biofuels

Commodities that are endogenous can be used as feedstocks for biofuel production processes offsetting fossil fuel usage and their GHG emissions. Three forms of biofuel production are included.

- Usage of switchgrass, poplar, willow, wood chips or mailing residues as inputs to electric generating power plants replacing coal usage.
- Usage of corn, switchgrass, poplar, or willow for conversion to ethanol and replacement of carbon emissions from petroleum usage.
- Usage of soybean oil or corn oil in the production of diesel fuel (xxxnote the above lists of commodities, GHG accounts, and processing alternatives does not reflect this).

In all these cases the GHG offset is the GHGs in the burning and producing the fossil fuel less the fossil fuel related emissions cost of producing the biofuel feedstock. The combustion emissions from the biofuels feedstock are not accounted as they are assumed to be offset by absorption of GHGs from the atmosphere by photosynthesis during plant growth.

3.10.4 Land to Development

FASOMGHG incorporates exogenous data that specify the rate of conversion of agriculture and forestry lands to nonagricultural and nonforestry developed uses. Simplified accounting is employed to estimate the carbon sequestered on these lands, as described in the GHG data sections of Chapter 13.

3.10.5 Non-GHG Environmental Indicators

FASOMGHG considers a number of environmental indicators above and beyond the GHG accounts. The main components are nitrogen and phosphorus runoff, soil erosion, irrigation water usage, and a number of descriptions of total resource use and activity within the agricultural and forestry sectors (total land use, total pasture use, manure load, livestock numbers, total afforestation, etc.). More information on these variables is provided in the Chapter on FASOMGHG output.

3.11 Temporal Scope and Dynamics

FASOMGHG is typically run as a 100-year model depicting land use, land transfers, and other resource allocations between and within the agricultural and forest sectors in the US The model solution portrays a multiperiod equilibrium on a five year time step basis. The results from FASOMGHG yield a dynamic simulation of prices, production, management, consumption, and GHG effects within these two sectors under the scenario depicted in the model data.

FASOMGHG incorporates expectations of future prices. Farmers and timberland owners are able to foresee the consequences of their behavior (when they plant trees or crops) on future stumpage and agricultural product prices and incorporate that information into their behavior. FASOMGHG uses deterministic expectations, or "perfect foresight," whereby expected future prices and the prices that are realized in the future are identical. Net present value related profit maximizing behavior is assumed.

The possibility of planting trees with a rotation length that would carry them beyond the explicit time frame of the model necessitates the specification of "terminal conditions". At the time of tree planting, producers should anticipate a flow of costs and returns which justify stand establishment costs. The planting of a timber stand with an expected 30-year life in year 80 of a 100-year projection is potentially problematic, however, because the anticipated harvest date is beyond the model time frame. A mechanism is needed to reflect the value of timber inventory carried beyond the explicit model time frame. This is done with "terminal conditions," which represent the projected net present value of an asset for all time periods beyond the end of the explicit model projection. Terminal conditions are resolved using downward sloping demand curves for the terminal inventory.

Several types of terminal inventory are valued in FASOMGHG: a) initial timber stands that are not harvested during the projection; b) reforested stands remaining at the end of the projection; and c) agricultural land retained in agriculture. Specific valuation approaches for each of these elements are discussed chapters 7 and 8 below.

3.12 Dynamic Yield, Cost, and Demand Updating

Features have been added to FASOMGHG to reflect changes over time in market and production conditions. Different updating procedures are used in agriculture and forestry as explained in the chapters on the forest and agricultural submodels below.

4 CHAPTER 4 ECONOMICS UNDERLYING FASOMGHG

A number of basic economic principals are involved in forming FASOMGHG and provide the assumptions under which it simulates behavior. These are explained in this section

4.1 Simulation of perfectly competitive behavior

FASOMGHG employs an approach originally motivated by Enke (1951) and Samuelson (1952) that was later it was fully developed by Takayama and Judge (1973). as explained in the literature review by McCarl and Spreen (1980). In this approach, an optimization problem is defined and solved using a set of equations that specify attainment of an economic equilibrium. Underlying this mechanism is the First Fundamental Theorem of Welfare Economics, which dictates that an allocation of resources that maximizes producers' profits, consumers' utility, and clears all markets, is Pareto Optimal (PO), an allocation which is at least as good as any other possible allocation. FASOMGHG is structured around the PO theoretical foundation and mathematical programming is used to maximize the sum of consumers' and producers' surpluses, subject to a set of supply demand balances, and resource restrictions, to ensure that the PO condition is met.

Mathematically, FASOMGHG solves an objective function to maximize net market surplus, represented by the area under the product demand function (an aggregate measure of consumer welfare) less the area under factor supply curves (an aggregate measure of producer costs). Such an approach involves solution of a nonlinear programming model and with endogenous product and factor prices. The resultant objective function value is consumers' plus producers' surplus.

Figure 4.1 Objective function representation

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The problem is now expressed in equation form. Suppose we have a demand curve

$P_d = f\,(Q_{d,})$ {xxxstart numbering the equations)

and a supply curve

$P_s = f\,(Q_{s,})$

In turn, for a perfectly competitive market we would have a set of market equilibrium conditions requiring prices and quantities to equilibrate

$P_d = P_s$

$Q_d = Q_s$

The mathematical programming approach to formulating such problems was motivated by Samuelson (1952), who suggested solving optimization problems whose first-order conditions constituted a system of equations characterizing an equilibrium. Suppose we follow this approach by first defining a system of equations, then posing the related optimization problem. In this case the equilibrium would simultaneously solve the equations

$$P_d = P_s$$

or

$$f(Q_d) = f(Q_s)$$

and

$$Q_d = Q_s$$

One should also recognize some possible peculiarities of the equilibrium. Namely it is possible that the markets could clear at zero quantity, in which case the supply price might be greater than or equal to the demand price. Thus, we can write the condition that the equilibrium price (P^*) is greater than or equal to the demand price

$$f(Q_d) \le P^*$$

Simultaneously, the market price may be less than the supply price,

$$f(Q_s) \ge P^*$$

One can also argue that these two relations should only be inequalities when the quantity supplied or demanded equals zero. Namely, when the demand price is less than the equilibrium price, then no quantity should be demanded. Similarly, when the supply price is greater than the equilibrium price, then no quantity should be supplied. Simultaneously, when a non-zero quantity is supplied or demanded, then the equilibrium price should equal the supply or demand price. This relationship can be expressed through complementary slackness relations where

$$(f(Q_d) - P^*)\ Q_d = 0$$
$$(f(Q_s) - P^*)\ Q_s = 0$$

One should also recognize that the quantity supplied must be greater than or equal to the quantity demanded

$$Q_s \geq Q_d$$

but, if the quantity supplied is strictly greater than the quantity demanded, then the equilibrium price should be zero. Mathematically this relationship is

$$(-Q_s + Q_d)P^* = 0$$

Finally, we state nonnegativity conditions for price and quantities,

$$Q_d,\ Q_s,\ P^* \geq 0.$$

The above equations are similar to Kuhn-Tucker conditions. In particular, if P^* is taken to be a dual variable, then the above equation system is equivalent to the Kuhn-Tucker conditions of the following optimization model

$$\begin{array}{llcll} \text{Max} & \int_0^{Q_d^*} f(Q_d)\, dQ_d & - & \int_0^{Q_s^*} f(Q_s)\, dQ_s & \\ \text{s.t.} & Q_d & - & Q_s & \leq 0 \\ & Q_d & , & Q_s & \geq 0 \end{array}$$

Where the Lagrangian and Kuhn -- Tucker conditions are

$$L(Q_d, Q_s, \lambda) = \int_0^{Q_d^*} \mathrm{f}(\mathrm{Q_d})\, d\, \mathrm{Q_d} - \int_0^{Q_d^*} \mathrm{f}(\mathrm{Q_d})\, d\, \mathrm{Q_d} - \lambda(Q_d - Q_s)$$

$$\frac{\partial L(Q_d, Q_s, \lambda)}{\partial Q_d} = f(Q_d) - \lambda \le 0$$

$$\frac{\partial L(Q_d, Q_s, \lambda)}{\partial Q_s} = - f(Qs) + \lambda \le 0$$

$$\frac{\partial L(Q_d, Q_s, \lambda)}{\partial \lambda} = -(Q_d + Q_s) \ge 0$$

$$\frac{\partial L(Q_d, Q_s, \lambda)}{\partial Q_d} Q_d = (f(Q_d) - \lambda) Q_d = 0$$

$$\frac{\partial L(Q_d, Q_s, \lambda)}{\partial Q_d} Q_s = (-f(Q_s) + \lambda) Q_s = 0$$

$$\frac{\partial L(Q_d, Q_s, \lambda)}{\partial Q_d} \lambda = -(Q_d - Q_s)\lambda = 0$$

$$Q_d, Q_d, \lambda \ge 0$$

and if P* is used in place of λ then the systems are mathematically the same.

Thus, solving the optimization problem generates a solution which is an equilibrium. In this problem, the area under the demand curve above the price line yields consumers' surplus, while, the total revenue (price times quantity) less the area under the supply curve yields revenue minus production cost, or producers' surplus.

4.1.1 Adding production

The above presentation was restricted to a single commodity with explicit supply and demand curves. However, one can depict commodity demand for multiple products without explicit supply for those products, but rather with a production process and factor supply for inputs. Such models have exogenous factor supply and product demand curves, but implicit factor demand and product supply. Such a model can be expressed as follows.

$$
\begin{array}{llllll}
\text{Max} & \sum_h \int_0^{Z_h} P_{dh}(Z_h)\, dZ_h - \sum_i \int_0^{X_i} P_{si}(X_i)\, dX_i & & & & \\
\text{s.t.} & Z_h & - \sum_\beta \sum_k C_{h\beta k} Q_{\beta k} & \leq & 0 & \text{for all h} \\
 & - X_i & + \sum_\beta \sum_k a_{i\beta k} Q_{\beta k} & \leq & 0 & \text{for all i} \\
 & & \sum_k b_{j\beta k} Q_{\beta k} & \leq & Y_{j\beta} & \text{for all j and } \beta \\
 & Z_h, \quad X_i, & Q_{\beta k} & \geq & 0 & \text{for all i, h, k and } \beta
\end{array}
$$

This problem assumes that a number of different types of firms (β) are being modeled. Each firm has a finite set of production processes (k) which depict particular ways of combining fixed factors (j) with purchased factors (i) to produce commodities (h). The symbols in the formulation are: $P_{dh}(Z_h)$ is the inverse demand function for the h^{th} commodity; Z_h is the quantity of commodity h that is consumed; $P_{si}(X_i)$ is the inverse supply curve for the i^{th} purchased input; X_i is the quantity of the i^{th} factor supplied; $Q_{\beta k}$ is the level of production process k undertaken by firm β; $C_{h\beta k}$ is the yield of output h from production process k; $b_{j\beta k}$ is the quantity of the j^{th} owned fixed factor used in producing $Q_{\beta k}$; $a_{i\beta k}$ is the amount of the i^{th} purchased factor used in producing $Q_{\beta k}$ and $Y_{j\beta}$ is the endowment of the j^{th} owned factor available to firm β.

An investigation of the Kuhn-Tucker conditions would show that the shadow price on the first and second rows are, respectively, the demand and supply prices. The conditions for the Q variable indicates that production levels are set so the marginal value of the commodities produced is less than or equal to the marginal costs of the owned and fixed factors for each $Q_{\beta k}$.

The model formulation assumes that: 1) the supply and demand equations are integrable; and, 2) product demand and factor supply functions are truly exogenous to the model.

The area under the product demand and factor supply functions makes the objective function equal consumers' plus producers' surplus, which is the net social benefit generated by the market exchange of these goods. The solution of the model generates equilibrium price and quantity for each output, and purchased input, along with the imputed values for the owned factors of production.

The model formulation assumes that the sector is composed of many micro-units, none of which can individually influence output or factor prices. Each micro-unit supplies output at the point where marginal cost equals product price, and utilizes purchased inputs at the point where the marginal value product of each purchased input equals its market price. Thus, the sectoral supply of output schedule corresponds to an aggregate marginal cost schedule, and the sectoral derived demand schedule for purchased inputs corresponds to the aggregate marginal value product schedule. Hence, the model does not take product supply or factor demand schedules as input, rather these schedules are derived internally based upon production possibilities, output demand and purchased input supply.

The competitive behavior simulating properties of this formulation provides a powerful tool for policy simulation. Except in centrally planned economies, the government cannot dictate production patterns consistent with its objectives. This formulation recognizes the difference and possible conflict between government and producer objectives (see Candler, Fortuny, and McCarl 1981 for elaboration). The model allows policies to be specified, then simulated in terms of projected sectoral response to the policy change. The model does not assume participants respond to government wants; each producer optimally adjusts so as to maximize profits. Producer adjustment is endogenous to the model.

4.2 Behavior over time using discounted NPV

Given the modeling of multiyear timber production, FASOMGHG needs to handle economic returns over time. This is done by solving for multiple interlinked market equilibria in adjacent five year periods for the model duration, rather than for just one single period (as would be the case in a static equilibrium model). The FASOMGHG objective function depicts maximization of the net present value of producers' and consumers' surpluses, associated with production and price formation in competitive markets over time for both agricultural and wood products. In that sense, the first-order (Kuhn-Tucker) conditions for the choice variables in the model provide a set of optimization rules for economic agents to follow, leading to the establishment of a competitive equilibrium.

Because these choices occur over time, the optimizing nature of the model holds that producers and consumers' have *perfect foresight* regarding future demand, yields, technologies, and prices. In other words, choices made at the beginning of the projection period are based on correct expectations of what the model predicts will occur in the future.

Perfect foresight employs the assumption that agents are rational and respond with the best information they have available at the time. This draws on well-established economic theories about rational expectations (Muth 1961) and intertermporally efficient capital markets (Fama 1970).

4.2.1 Discounting

The multiperiod nature of the economic problem requires transforming future revenues and costs to the present using a real (inflation-adjusted) *annual discount rate*. The default rate used is 4 percent, which is broadly consistent with opportunity costs of capital in agriculture and forestry. The default rate can be altered to test the sensitivity of model results to alternative discount rates. Higher discount rates devalue future revenue and cost streams. Because forestry is an enterprise with revenue streams that are deferred often several time periods beyond the incidence of initial establishment and ongoing management costs, forestry returns can generally be expected to be particularly sensitive to the chosen discount rate. Moreover, the discount rate can significantly affect the timing of land use, investment and harvest decisions with effects reaching broadly across both sectors in the model.

4.2.2 Need for terminal conditions

Given that the model is defined for a finite time period (e.g., 70-100 years), there will be immature trees of some age at the end of the time period modeled. If the model did not place a value on these forests, the optimizing nature of the model would be inclined to deplete all timber at the end of the projection period rather than leave it around for future harvests. Similarly, agricultural land values at the end of the period must also be considered to ensure that land is not inappropriately converted as a result of a perceived lack of opportunity cost.

To counter these ending-period anomalies, *terminal conditions* are imposed on the model that value ending immature trees and land remaining in agriculture. FASOMGHG assumes that forest management is, from the last period onward, a continuous or constant flow process with a forest inventory that is fully regulated on rotations equivalent to those observed in the last time periods of the projection (see Adams et al. [1996]). Demand functions for timber are used in this period assuming that the fully regulated volume persists forever. The terminal value of land remaining in agriculture is formed by assuming that the last period persists forever.

4.3 Dynamics of harvest

FASOMGHG endogenizes the harvest date for a timber stand, assuming it is past an exogenously determined region-specific minimum harvest age. The harvest alternatives are differentiated by the model's five year time periods. Thus a 40 year old Pacific Northwest-westside (PNWW) timber stand (which is beyond the minimum harvest age for that region) could be harvested now, five years from now, ten years from now, etc. The decision whether to harvest a stand or extend it until the next period depends on whether the discounted value of its five year growth plus the value of any price change by extending the harvesting period exceeds the discounted cost of holding it into the next period, which consists of any realized production costs plus the difference in the opportunity cost of the land. The value of the timber when withheld from current harvesting is the price five years from now times the yield at that point. Naturally this is taken into account in the optimization for all the possible future harvest periods.

4.4 Land exchanges

FASOMGHG reflects the mobility of the land resource between the two sectors subject to controls for land quality/growing conditions, investments needed to mobilize land, and hurdle costs consistent with observed behavior. The land quality factors generally restrict some lands to only be in forest, due to topography or soil characteristics. Likewise, the growing conditions render some lands unsuitable for forest uses at all, particularly in the drier plains areas of the country, and would thus be suitable only for some agricultural uses.

The investments to mobilize land from forest to agriculture generally involve stump clearing, leveling, etc. of forested lands and result in a three step depiction of land transformation processes. The hurdle costs reflect costs to move land between uses where for example it may take an income differential above and beyond the opportunity cost in agriculture to get agricultural producers to switch to forestry. Such evidence is based on the econometric findings of Lubowski, Plantinga and Stavins (xxxcite).

Given these model attributes, the economic conditions for land movement are that when land moves into forestry, the net present value of the returns from one rotation in forestry plus the future value of forest land beyond the first rotation must be greater than the net present value of the land remaining in agriculture by at least the hurdle cost. For land moving from forest to agriculture, the net present value of land in agriculture must exceed returns to a rotation in forestry plus the future value of forested land by the investment cost to transfer land plus any hurdle cost (this term is currently set to zero). In both land transfer cases, the land moves between sectors until the markets equilibrate and the net present value plus the investment and market wedges are equal across the sectors for lands on the margin. Naturally, land movement does not occur if the differences in the land returns are less than the hurdle cost plus the land transformation investment costs.

4.5 Commodity exchanges between sectors

FASOMGHG also reflects movement of commodities between the forest and agriculture sectors, largely in the form of biofuels and short rotation woody crops. In particular, agriculturally produced short rotation poplar can be chipped and move into pulp and paper production processes and milling residues, pulp logs and in some cases logging residues can move between sectors as raw material sources for finished products made in the other sector.

4.6 Aggregation, Calibration profits, and mixes

All economic models must deal with aggregation and calibration at some level, but these issues are particularly important in agricultural sector models where great heterogeneity of growing conditions, resource quality, market conditions, and management skills are present. The aggregation problem involves treating groups of producers operating over aggregated resource sets as homogeneous units. The calibration problem involves dealing with spatially disaggregate producers who are entrants in a single market but receive different prices.

4.6.1 A discussion of calibration, aggregation and sectoral models

Suppose we formulate an aggregate programming model that represents a group of farms in a region, as in Model 1.

$$\underset{x}{MAX}\ (\mathrm{r} - \mathrm{c})x$$

ST **Model 1**

(1) $Ax \leq b$

(2) $x \geq 0$

Also suppose the true real-world situation on one of the farms represented in Model 1 is actually described as shown in Model 2.

$$\underset{x}{MAX}\ (\mathrm{r} - \mathrm{c} - \mathrm{d} - \mathrm{e}x)x$$

ST

(3) $Ax \leq b$ **Model 2**

(4) $Dx \leq f$

(5) $x \geq 0$

The notation in both models is:

- x An aggregate vector of crop acreages.
- r A vector of average revenue.
- c Variable costs related to the crop acreage, which are *included* in both models. These costs normally include the costs reported in accounting statistics, such as fertilizer, seed, tilling, pesticide, energy and labor costs.

- d Variable costs taken into consideration by the farmer, which are *not included* in Model 1. These may include marketing costs, for example.
- e Variable costs that increase with increasing area of the crop and or revenue declines associated with the rate of decline in the yield with increasing area of the crop. These items occur due to increased disease pressure, marginally decreasing soil quality, etc. These items are taken into consideration by the farmer but are *not included* in Model 1.
- A A matrix of technical coefficients, which are *included* in both models.
- b A resource vector corresponding to matrix A.
- D A matrix with technical coefficients, which are *not included* in Model 1.
- f A resource vector corresponding to matrix D.

As the models are described here, there are important differences. The underlying cause for the omissions in Model 1 is the lack of full information about farm resources and costs, transaction costs, incentives and market conditions. These differences make calibration and aggregation necessary. Adding relevant information to Model 1 could reduce the problem. One could imagine that if all relevant information were added, the model would not only calibrate correctly to current production, but also to all counterfactual scenarios, since the incentives and production possibility representation are correct. However, when a model is expanded from describing a few farms to the sector or society level, the costs of gathering and maintaining an adequate amount of information for all the included cases are enormous.

The differences between the sector model in Model 1 and the real world as illustrated in Model 2 may be due to reasons discussed in the following subsections.

4.6.1.1 Sector models typically depict groups of farms

Usually, a large number of farms of a particular type in a geographical region such as a state or province are represented as a single typical farm. Thus, models contain, for example, a single submodel representing all corn-soybean farms in Iowa, or all dairy operations in Sweden, even though there may be hundreds or even thousands of such types of farms, each with different characteristics. The construction of such typical farms introduces aggregation, and is done as a result of data and model size considerations.

4.6.1.2 Resource availability details

Typically, there are submodels within sector models, and these are highly aggregated representations of the operations they depict. They involve annual land, labor and water availability without considering many, or sometimes any, of a large variety of farm-specific factors such as crop rotation, quality of labor, land type, implementation and tractor time constraints. For example, in modeling an Indiana corn-soybean-wheat-silage farm, the farm level model employed by McCarl *et al*. (1977) had more than 200 production possibilities and more than 175 resource-related constraints. In contrast, FASOMGHG represents all of Indiana production, including livestock production potential, with less than two dozen production possibilities and a dozen constraints. Data and model size considerations force such an aggregate depiction.

4.6.1.3 Sector models typically ignore certain market factors.

Typically, more aggregate models depict regional producers and consumers' as if they traded a set of homogeneous commodities at a single commodity-specific price. However, it is commonly observed that prices for a single commodity such as hay vary within any region across the places in the region as well as by time of sale and commodity quality characteristics. Therefore, the notion of a single market price for a commodity is an abstraction of reality.

4.6.1.4 Data availability forces aggregation on the modeler

Typically, sector-modeling exercises requires the use (and possibly the development) of consistent data on a national basis. When trying to use or develop such data, one usually finds that crucial items such as crop production budgets are available for average or typical regional operations, but not for a large number of possible alternative enterprises. Confidentiality and the costs of finer data development generally preclude more detailed data sets. Price data are also typically averages over regions, days, sale contract terms and grades, as are consumption data.

4.6.1.5 Differences exist between the producer problem and the model

Models often depict profit maximization subject to resource constraints as the sole objective of the producer, excluding other potentially important factors. Examples of relevant excluded considerations include risk aversion, financial reserves, capital constraints, personal expectations concerning yields and prices, and non-market objectives that are important to the producer (e.g. stewardship, tradition, wildlife habitat provision). These are all difficult to measure and depict on an aggregate scale.

4.6.1.6 Insufficient depiction of production possibilities in budgets

The model’s producer level farm budgets give statistically based data describing production practices carried out at one point in time on average. This reflects practices as they were not how they could have been. Consequently, budgets do not give a full spectrum of possible production responses. Also, time lags in budget availability (i.e. with those available being one or two years old) and geographical averaging may introduce bias in model response.

4.6.1.7 Specialization and mathematical programming solutions

Mathematical programming solutions, particularly those from linear programming models, tend to produce extremely specialized solutions ("corner solutions"), wherein only one activity might be selected from a wide range of options for a rather large segment or region of the model. Thus, model solutions may be generated which give regions as producing only part of the crop and livestock potential production which is actually common within the boundaries of the region. The extent of this problem will be determined by the number of production possibilities employed and by the richness of the constraint set and the embodied production possibilities. Because this single corner solution often runs counter to what is observed in the field, this sometimes introduces concerns about the model's realism unless addressed by model design.

4.6.1.8 Transaction costs are often omitted

Many models are built on the basis of farm budgets, but then use consumer or regional-level average prices to calculate economic returns. There are costs accruing in the marketing channel for handling and transport that are frequently not present in budgets, so there are often price differentials between farm level prices received and prices paid by consumers' which are not fully captured in models.

4.6.2 Addressing the aggregation problem

As indicated above, the aggregation problem involves depicting production responses across a group of producers as a single response. Namely, within a FASOMGHG agricultural subregion such as Oregon, each farmer is represented by a single aggregate set of production variables facing an aggregate quantity of land by type, water, labor, AUMS, etc. Such a situation clearly is a simplification of reality as producers in such regions face different climatological and other conditions. But availability of data and considerations of sheer model size make some degree of aggregation both desirable and necessary. In practice, virtually every national scale model contains simplifications of reality, omitting potentially important information which is taken into consideration by farmers when choosing a farm plan. However, the need to enhance a model's sectoral, geographic, and temporal coverage and detail in a conceptually consistent manner requires such abstractions to be made.

Clearly time and data would not permit trying to depict the production system for all farms. Nor, if it were done once, could one afford to maintain such a data set over time. This raises the classic concern of aggregation. However, the usual objective in applying FASOMGHG and other similar models is to develop a representation of the production choices at a regional (then national) scale to gives an accurate and credible portrayal of how the region might respond to changes in policy. If, instead, the objective was to model how individual farms with highly specific characteristics would respond, a finer scale model would be necessary. The aggregate representation of FASOMGHG, though, should be designed so that it exhibits minimal differences between what would happen if we had a full regional representation vs. the more compact regional representation we choose to use. Such a choice obviously is hampered by the fact that we never know the full characteristics of the region.

Agricultural economists have spent much time addressing aggregation issues, yielding two primary approaches to the problem. First, there are *bottom-up* theoretical and empirical investigations. Here one assumes s(he) has data on individual farms or firms and wishes to develop a representation which exhibits minimum bias (as typified by Day, 1963a,b, 1969a,b). Second, are the *top down,* more empirical approaches with theoretical justification. Here one assumes s(he) doesn't know the data on the individual farms/firms but can get more aggregate data and wishes to appropriately use that data to represent activity for the population represented in the model.

Some have tried empirical approaches motivated by Day's bottom up work to classify farms into groups and develop models for those groups based on most limiting resources. In addition, formal pursuit of these approaches requires much more data than is typically available about crop choice and production economics for all of the farms in a region. This has led to the more general and loose empirical approach where one classifies farms in a region based on expert opinion, then generates models for those different farm classifications. Unfortunately, the Day based approach did not prove useful empirically and was not chosen for use in FASOMGHG. Farmers even under very similar conditions and crop mixes generally have different price expectations, equipment complements (resulting in different working rates), and different access to resources.

The second (top down) approach is used in FASOMGHG. FASOMGHG requires a regional representative model to choose among a convex combination of typical crop mixes as will be illustrated in the agricultural modeling section below. The rationale behind this approach can be argued from two different standpoints.

4.6.2.1 Justification 1: Observed practices reflect constrained choices

In production economics, duality theory asserts that supply equations can be identified by estimating the relationship between profit (or cost) and determining factors (such as prices), using theoretically based deduction. In agriculture, then, the supply function is implicitly revealed through the observed farm profit-seeking choices.

Similarly, farm crop mix choices implicitly have embedded in them the farm's full consideration of all production possibilities and the constraints imposed by rotation, resources, and other technical factors. As a consequence forcing a combination of observed crop mixes**,** implicitly incorporates all firm production processes and constraints.

4.6.2.2 Justification 2: Theory indicates use of approach solves problem

The solution to a mathematical programming problem appears at what is called an extreme point. Such a point lies on the constraint boundary at an intersection point between separate constraints. Dantzig and Wolfe (1961) investigated solutions to problems which have a unifying regional market but contain individual submodels for every firm. They showed that the overall problem solution could be composed from the optimal crop mix solutions from the firm-level problems without consideration of firm level constraints. They showed that the firms could be represented as a convex combination of solutions to firm problems, i.e., a convex combination of optimal crop mixes, which obey the firm-level constraints.

This approach involves a reformulation of the programming model. The reformulation approach is based upon Dantzig and Wolfe decomposition and suggestions in McCarl (1982). Dantzig and Wolfe based their scheme on the property that the solution to a subproblem or group of subproblems will occur at the extreme points of the subproblem(s). Thus, one can reformulate the problem so that it contains the extreme point solutions from the subproblems. Formally this can be expressed as follows. Given the problem as expressed above

$$
\begin{array}{llllll}
\text{Max} & \sum_h \int_0^{Z_h} P_{dh}(Z_h)\, dZ_h - \sum_i \int_0^{X_i} P_{si}(X_i)\, dX_i & & & & \\
\text{s.t.} & Z_h \qquad - \sum_\beta \sum_k C_{h\beta k} Q_{\beta k} & \le & 0 & & \text{for all h} \\
 & - X_i + \sum_\beta \sum_k a_{i\beta k} Q_{\beta k} & \le & 0 & & \text{for all i} \\
 & \sum_k b_{j\beta k} Q_{\beta k} & \le & Y_{j\beta} & & \text{for all j and } \beta \\
 & Z_h, \quad X_i, \quad Q_{\beta k} & \ge & 0 & & \text{for all i, h, k and } \beta
\end{array}
$$

suppose we group the firms β into subsets $r_m(\beta)$ where r_m depicts the m^{th} aggregate firm grouping. In turn, suppose we have a set of s feasible solutions $Q_{\beta k}$ and add up their aggregate levels of production and input usage such that

$$Z_h^{ms} = \sum_{\beta \in r_m(\beta)} \sum_k C_{h\beta k} Q_{\beta k}^s \quad \textit{for all } m, h, \textit{and } s$$

$$X_i^{ms} = \sum_{\beta \in r_m(\beta)} \sum_k a_{i\beta k} Q_{\beta k}^s \quad \textit{for all } m, i, \textit{and } s$$

This in turn can be used in the aggregate problem:

$$\begin{array}{llllllll}
\text{Max} & \sum_h \int_0^{Z_h} P_{dh} (Z_h)\, dZ_h & - & \sum_i \int_0^{X_i} P_{si} (X_i)\, dX_i & & & & \\
\text{s.t.} & Z_h & & & - \sum_m \sum_s Z_h \lambda_{ms} & \leq & 0 & \text{for all h} \\
 & & - & X_i & + \sum_m \sum_s X_i^{ms} \lambda_{ms} & \leq & 0 & \text{for all i} \\
 & & & & \sum_s \lambda_{ms} & \leq & 1 & \text{for all m} \\
 & Z_h, & & X_i, & \lambda_{ms} & \geq & 0 & \text{for all i, h, m and s}
\end{array}$$

This model differs in two major ways from those above. First, the firm response variables have data requirements not in terms of individual production possibilities, but rather in terms of total production and consumption of the sector wide outputs and inputs accumulated across the firms in each group. In addition, rather than using individual resource constraints we now require a convex combination of the total output/input vectors. This will be feasible in the subproblems since any combination of two feasible subproblem solutions is feasible. Implicitly these solutions contain all the firm level resource restrictions and production possibilities coded within them.

The candidate solution vectors (i.e., the values of X_i^{ms},Z_h^{ms}) must be developed. These can be generated either by formally solving the linear programming subproblems for different prices or by selecting a historical set of observed feasible mixes or firms. This is discussed further in Onal and McCarl (1989, 1991). Furthermore crop mixes of individual firms are not needed but rather can use mixes from groups of firms such as all farms in a county.

McCarl, Hamilton, and Adams (1985) investigated the effect of different representation schemes in a Midwest region study felt through changes in crop yields and resultant effects on regional welfare. That study looked at crop mixes derived from a set of 13 typical farm LP models as well as a set of crop mixes drawn out of the USDA Agricultural Statistics publications. A regional model based on the agricultural statistics crop mixes generated virtually the same information as the much more time and resource intensive linear programming representative farm-based crop mixes, thereby providing evidence that aggregate data on crop choices are consistent with underlying profit-maximizing choices.

There are some basic problems with this approach, however. First, the use of historical crop mixes does not constitute as rich a production possibility set as one would have with the full detail in a model which more completely represented individual units. Historical crop mixes are reflections of producer decisions in the face of prevailing prices. Thus the crop mixes will not be an accurate representation either if the expected prices confronted by the model are well outside the historical range or if the situation to be examined substantially revises the production possibilities. Önal and McCarl (1989) found that when the prices and product mixes were not substantially different, the historical mixes gave a solution very close to that produced by more disaggregated modeling schemes. Others have attempted to correct such problems by augmenting the historical crop mix information with expert opinion or survey information. Tanyeri-Abur *et al*., (1993) added additional crop mixes containing much less sugar when examining US sugar import policy. Apland and Jonasson (1992) followed a similar approach in eliminating oil crops. Schiable *et al*., (1999) added additional mixes from a farm survey in a study of farm policy revision, with the mixes being based on survey questions about reactions to policy revisions.

Another problem with this approach is that it does not take account of changes in production costs, inputs and yields when crop mixes change. A farmer knows that crop yields depend very much on the land use the previous year. Furthermore, costs may also vary with the previous crop. Some crops assist in avoiding diseases, thereby reducing the need for pesticides or other crop protection, while other crops have the opposite effect. These cost and yield changes are not taken into account.

4.6.2.3 Omitted costs -- profit calculation

Producers scattered throughout the country all receive different prices because they sell goods at different times, in potentially different quality forms and at different distances from marketing channels. Economic theory addresses this with the *Law of One Price*. This theory posits that all price differences are caused by different transactions costs and that once these transaction costs are all taken into account, all goods trade at effectively the same price. For if the same good traded at different effective prices, there would be opportunities for agents to engage in arbitrage and profit merely by exchanging goods sold at different prices. Market forces tend to dissipate these arbitrage opportunities.

The notion of adjusting prices to adequately reflecting transaction costs causes problems when using production budgets as the source of input data. In particular production budgets do not typically contain marketing transactions costs. It also causes problems when the demand function price is based on national statistics, because there are regional markets with higher prices caused by extra transactions costs that would net out any nominal price differences across regions.

The law of one price is assumed herein where the marginal returns from all production variables based on observed budgets are equated to the marginal costs plus missing cost items. FASOMGHG is structured based on farm production budgets and USDA Agricultural Statistics national average prices. In these budgets the prices received exhibit regional differentials. Furthermore, the USDA national average prices are also different. Under these circumstances, the decision was made to rely on the economic theory of competitive markets and structure the model so that the marginal cost of production at current levels of production equaled the marginal cost of production. This led to the missing costs calculation based on an idea originally expressed by Miller and Miller (xxxcite) and later utilized by Fajardo et al (1981). Each production and processing budget comes from actual production activity that was undertaken during the year that the budget was collected. When production budgets are collected, the data do not reflect the whole production possibility set, rather they reflect the actual production patterns. As such, in the base year one needs to assume that these goods are being produced optimally, given the price that prevails in the national market. Consequently, a transactions cost term is computed for each budget which equates the marginal value of its output and the marginal cost of input. Thus, for a corn production activity which uses land, labor, water and miscellaneous inputs, a profit term can be calculated which is equal to the base period corn price times base period corn yield minus the base period water price times the amount of water used minus the rental rate of land times land used minus the prevailing labor wage rate times labor used minus the sum of the other input prices times quantity used

TC=Price*Yield-Factorcost*FactorUsage

This cost term represents missing transaction costs. If one solves the model adding this cost term then when the shadow prices in the model equal the base period prices for crops and factors - this model has zero reduced costs. Consequently such a solution is a candidate solution in the FASOMGHG programming model. Summarizing this transactions cost is computed as a residual and then is added as a term in both the crop and livestock activities permitting the model to reproduce observed market prices and replicating regional pricing and production patterns.

SECTION 3: THE FASOMGHG PROGRAMMING MODEL

This section presents discussion of the structure of the programming model within FASOMGHG. We will do this by highlighting model components including the forest sector submodel, the agricultural submodel, the GHG payment submodel and the intersectoral features

this is not complete

5 CHAPTER 5: OVERALL FASOMGHG PROGRAMMING MODEL STRUCTURE

Operationally, FASOMGHG is a dynamic, nonlinear, price endogenous, mathematical programming model. FASOMGHG is dynamic in that it solves for the simultaneous multi-market, multi-period equilibrium across all agricultural and wood product markets, for all time periods, and thus for the intertemporal, intersectoral land market equilibrium. FASOMGHG embodies a nonlinear objective function, representing the sum of producers' and consumers' surpluses in all of the included product and factor markets. It is price-endogenous because the prices of the products produced and the factors used in the two sectors are determined in the model solution. Finally, FASOMGHG is a mathematical programming model because it uses numerical optimization techniques to find the multi-market price and quantity vectors that simultaneously maximize the value of an objective function, subject to a set of constraints. The FASOMGHG equations characterize: (a) the transformation of resources into products over time; (b) initial and terminal conditions; (c) the availability of fixed resources; (d) generation of GHG net emissions; and (e) policy constraints. The first-order (Kuhn-Tucker) conditions for the choice variables provide a set of rules characterizing the establishment of a competitive equilibrium.

An overview of the model is presented in three tableaus below:

- One of which covers sectoral scope in a static sense
- One of which is more aggregate but introduces the spatial/regional dimension
- The last of which is more aggregate but introduces the intertemporal dimension.

5.1 Static, single region portrayal

The tableau within table 5-1 shows the full scope of the FASOMGHG programming model in a single region, single time period setting. Although the tableau is designed to illustrate the most important model features, the reader should be aware that there is substantially more to the model. The subsequent chapters provide additional detail, as does the GAMS code.

Table 5-1 Sample tableau illustrating full FASOMGHG model in a static setting without regional detail

Equations / Variables	Exist stand	Reforest land	Afforest land	Wood production cost	Manufacture wood prods	Terminal manufacture	Forest domestic transport	Endog public supply (Cana	Non-wood inputs	Wood product demand	Wood product export	Wood product import	Terminal for product dema	Crop land from ag	Pasture land from ag	Land to ag crop land	Land to ag pasture land	Move for to ag commod	Move ag to for commod	Initial tillage	Change tillage	Produce crops	Produce livestock	Agricultural processing	Blend feed	Sup water, AUMs Labor	Crop/pasture exchange	Crop/livestock mix	Ag export	Ag import	Ag domestic consumption	Domestic ag transport	GHG payments	
Welfare				-pc			-fdt	-fds	-fnw	+fd	+fe	-fi	+ft	-alt	-alt	-flt	-flt	-fcm	-acm			-acc	-alc	-apc	-afc	-afs	-ale		+ae	-ai	+ad	-adt	+gp	
Exist timberland	+1																																	≤ Lf
Bare forest land	-1	+/-1	-1													+1	+1																	≤ -dev
Bare land from ag			+1											-1	-1																			≤ 0
Harvested log bal	-fhe	-fhr	-fha		+fpu			-1																										≤ usps
Min hardwoods	+1	+1	+1																															≥ mh
For production cost	+fce	+fcr	+fca	-1																														≤ 0
Wood products bal					+/-p		+/-			+1	+1	-1						+fm	-fm															≤ -exp
For process capacity					+1	+1																												≤ fcap
Mill residues bal					+/-m	+/-m																												≤ 0
Non-wood input bal					+1	+1			-1																									≤ 0
Terminal for inventory	-te	-tr	-ta			+fpu		-1																										≤ 0
Terminal for prods						-1					+1	-1	+1																					≤ 0
Initial crop land																				+1														≤cl
Land that can change till														+als		-als				-1	+/-1						+/-1							≤-devc
Tilled land														+als		-als				-1	+/-1	+1					+/-1							≤-devc
Pasture land															+1		-1						+pu				-/+1							≤pl
Crop balance																		-am	+am			-cy	+cu	+pc	+fc				+1	-1	+1	+/-1		< 0
Livestock balance																							+-ly	+pl					+1	-1	+1	+/-1		< 0
Processed ag commod																							+su	+-py	+fs				+1	-1	+1	+/-1		< 0
Feed balance																							+fu		-1									< 0
Water, AUMs, labor																						+cl	+ll			-1								< 0
Crop mix																						+1						-cm						= 0
Livestock mix																							+1					-lm						= 0
Max for land transfer														-1	-1	+1	+1																	≤ltf
Max ag land transfer														+1	+1	-1	-1																	≤ltc
GHG balance	ce	cr	ca		Cm									-as	-as	as	as			ts	tcs	ce	le	pg			ds						-1	= 0

The tableau shows that the FASOMGHG programming model encompasses four submodels and an integrating objective function:

- **Forestry sector submodel –** Covers forest sector production, manufacturing, input supply, consumption, interregional transport, international trade, and terminal inventory valuation. This submodel is represented by the tableau columns labeled *Exist stand* through *Terminal for product demand.* The feasible solution values for the forestry submodel variables are limited by constraints on land; input/factor supply; log supply/demand balances; intermediate and final product balances; processing capacity; and terminal inventory valuation. This is represented by the tableau rows *Exist Timberland* through *Terminal for prods.* The forestry submodel also affects the GHG balance as is shown in the last row of the tableau.
- **Agricultural sector submodel** – Covers agricultural sector crop and livestock production, processing, feed blending, factor supply, consumption, interregional transport and international trade including terminal valuation of land remaining in agriculture. This submodel is represented by the tableau columns labeled *Initial tillage* through *Domestic ag transport.* The feasible solution values for the agricultural submodel variables are limited by constraints on crop and pasture land; factor supply; supply/demand balances on crop, livestock, processed and blended feed products; and crop/livestock mixes. This is represented by the tableau rows *Crop land* through *Livestock mix.* The agricultural submodel also affects the GHG balance as is shown in the last row of the tableau.
- **Intersectoral transfers submodel** – Covers transfers of land and commodities between the forestry and agricultural sectors. This submodel is represented by the tableau columns labeled *Crop land from ag* through *Move ag to for commod.* The first four columns depict land transfers and the last two commodity transfers. Land transfers are limited by the equations *Max for land transfer* and *Max ag land transfer.* The submodel variables have entries in the land availability and commodity balance equations within the forestry and agricultural submodels.
- **GHG submodel – Covers** GHG accounting and payments to net GHG emission reductions from agriculture and forestry. The GHG accounts reflect sequestration activity, emission activity, and biofuel related offset activity. In the tableau, the GHG submodel is represented by the column *GHG payment* and the row *GHG balance*. The *GHG balance* row depicts the involvement of agricultural and forestry activities. In turn, given a policy or GHG price signal these submodels can employ different production possibilities to reduce net GHG emissions.
- **Integrating objective function** – Net present value of consumers' and producers' surplus across all four submodels. This is maximized in the FASOMGHG solution. The objective function is the tableau row labeled *Welfare*. Positive contributions arise over time and in the terminal period in association: (a) the area underneath the demand curves

for domestic consumption and export of forestry and agricultural products; (b) the valuation of terminal forest inventory and (c) the GHG payments to net emission reductions. In turn, total cost is subtracted in the form of cost terms and the areas underneath supply curves. The upward sloping supply functions include (a) forestry non-wood inputs, (b) agriculture and forestry imports, and (c) agricultural factor supplies for water, AUMs, and labor.

Next we discuss components of each of the four submodels separately, including the submodel components within the objective function.

5.1.1 Forestry sector submodel

The forestry sector submodel depicts forestry production, processing, input supply, consumption, interregional transport, international trade, and terminal inventory valuation. This submodel is represented by the tableau columns labeled *Exist stand* through *Terminal for product demand.* The feasible solution values for the forestry submodel variables are limited by constraints on land; input/factor supply; log supply/demand balances; intermediate and final product balances; processing capacity; and terminal inventory valuation. This is represented by the tableau rows *Exist Timberland* through *Terminal for prods.* The forestry submodel also affects the GHG balance as is shown in the last row of the tableau. Next we discuss each variable (column) depicted in the tableau along with each equation (row).

The variables in Tableau 5-1 that make up the forestry submodel are:

- Exist stand -- Allocation of acres to forest production alternatives for stands that exist at the beginning of the model run. The variable involves determination of the time of harvest, with one possibility being that the stand ia never harvested. Forest stands are differentiated by region, land class (reflecting suitability for agriculture), site quality, type of forest stand (softwoods, hardwoods, planted pine, etc.), type of private forest owner (industrial or nonindustrial private), age of stand, and prior stand management (including prior fertilization, partial cut and thinning regimes). The variables reflect usage of forest land from the existing inventory. If clearcut, they yield an acre that can be reforested. They also fall into the hardwood minimum constraint provided that hardwoods are being grown. In periods of clearcut, thinning, or partial cut, they produce harvested logs depicted by **fhe,** while they incur production costs (**fce)** from the initial model time period up to the period of clearcut. If these stands are never harvested during the explicit model time periods or are partially cut, they yield terminal inventory equal to **te.** Finally, they enter the GHG balances between the first period and the period just before clearcut at the rate **ce**, reflecting: (a) GHG sequestration in soils, ecosystems, and standing timber and (b) fossil fuel emissions incurred during production**.** Within the GAMS implementation these are the variables ***FORPRDEXIST***.

- Reforest land -- Acres allocated to reestablished forest on previously clearcut lands. They involve determination of harvest time (with never being a possibility), type of forest (softwoods, hardwoods, planted pine, etc.), and management applied (including possible fertilization, partial cut, and thinning regimes). These variables are defined by time of forest reestablishment, time of harvest, and land characteristics. The land characteristics involve region, land class in terms of suitability for agriculture, site quality, and type of forest owner. In turn, if clearcut, these stands yield acres that can be reforested. They also fall into the hardwood minimum constraint provided that hardwoods are being grown. In periods when the stand is clearcut harvested, thinned, or partially cut, they produce harvested logs depicted by **fhr,** while they incur production costs (**fcr**) across time from the establishment period to clearcut period or the model end. If these stands are not clearcut, they yield terminal inventory **tr.** Finally, they enter the GHG balances (**cr**) between time of stand establishment up to just before clearcut, reflecting sequestration, and fossil fuel emissions incurred during production**.** Within the GAMS implementation these are the variables ***FORPRDNEW***.
- Afforest land -- Afforestation of acres to forest production alternatives on land transferred from agriculture. They involve determination of harvest time, forest type (softwoods, hardwoods, planted pine, etc.), and management applied including possible choice of partial cut or thinning regime. These variables are defined for the time period of afforestation, clearcut harvest period, and land characteristics. Land is controlled by region, suitability for agriculture, and site quality (High or Medium). All afforested land is assumed to belong to nonindustrial private forest owners. The variables use one acre of land transferring in from agriculture. In turn, if clearcut, they yield an acre into the bare land equation. They also fall into the hardwood minimum constraint provided that hardwoods are being grown. When the stand is subjected to clearcut harvest, thinning, or partial cut, it produces harvested logs (**fha**), while incurring production costs (**fca**) from the periods of establishment through the clearcut period. If these stands are never clearcut harvested, they yield terminal inventory (**ta**). Finally, they enter the GHG balances (**ca**) during the periods between establishment up to just before the clearcut period, reflecting sequestration, and fossil fuel emissions incurred during production. Within the GAMS implementation these are the variables ***FORPRDNEWAFFOREST***.
- For production cost -- Total stand production costs in dollars by each region and time period. The variables equate with the costs incurred in the production cost balance equation and incur an objective function entry (**pc**). Within the GAMS implementation these are the variables ***FORPRDCOST***.
- Manufacture wood prods -- Quantity of wood product manufacturing (processing) activity in units of product made by region, type of product, type of process, input mix,

and time period. These variables not only embody manufacturing, they also incorporate: (a) log harvest and forest to mill hauling, and (b) product transformation including downgrading of logs, such as from sawtimber to pulpwood. This variable is defined for all FASOMGHG wood product manufacturing regions, including those in Canada. Logs are used as inputs at the rate **fpu,** while wood products are produced and possibly used at the rate **p,** generating or using milling residues (**m**). Processing capacity is used. They also require one unit from the regional and process specific non-wood input balance, which in turn reflects an upward sloping supply curve of non-wood inputs. Finally, they enter the GHG balance (**cm**) in the period of wood product manufacture and all subsequent periods, reflecting carbon sequestered in manufactured wood products. Within the GAMS implementation these are the variables ***FORWDMANUFACT***.

- Terminal manufacture – Terminal-period activity of wood product manufacturing by region, wood product made, process, and input mix. The variables have the same characteristics as the above *Manufacture wood prods* variables, with the only real difference being that the logs come from the terminal inventory balance equation**.** Within the GAMS implementation these variables fall within ***FORWDMANUFACT***.
- Forest domestic transport -- Quantity of wood products transported between regions. The variable is defined by product type, originating region, destination region, and time period. They reflect transport cost in the objective function (**fdt**), while using one unit of wood product in the region of origin and supplying one unit into the region of destination. All regions are covered where wood products manufacture is defined, including those in Canada. Within the GAMS implementation these variables fall within ***FORWDTRANSPORT***.
- Exog public supply (Canada)—In Canada only, public supply (from provincial lands) of harvested logs by region, time period, and log type. They reflect cost of supply in the objective function (**fds**), and supply one unit of logs into the harvested log balance. Within the GAMS implementation these variables are named ***FORWDLOGSUPPLY***.
- Non-wood inputs -- Supply of non-wood input items for wood product manufacturing. They are defined by wood product, process, region, and time period. They depict an upward sloping supply curve for non-wood input items. Non-wood inputs include those for manufacturing inputs, harvest, and woods to mill hauling costs. The variables have objective function coefficients (**fnw**) reflecting subtraction of a term representing area underneath the non-wood input supply equation and supply one unit into the non-wood input balance equation. Within the GAMS implementation these are the variables ***FORWDNWCS***.
- Wood product demand -- Wood product demand by type of wood product at the US national level by time period. They represent a downward sloping demand curve. The variables fall into the objective function, with a term (**fd**) reflecting the area underneath the demand equation. They also reflect the withdrawal of one unit from the wood product

balance equation. Within the GAMS implementation these variables are cases within ***FORWDDEMAND***.

- Wood product import -- Import supply of wood products (softwood lumber from non-Canadian sources only) at the regional level by time period. They represent an upward sloping import supply curve. These are defined for each wood product manufacturing region. The variables fall into the objective function with the subtraction of a term (**fi**) reflecting the area underneath the import supply equation. They also add one unit to the wood product balance. Within the GAMS implementation these are within ***FORWDSUPPLY***.
- Terminal for product demand -- Terminal period demand for wood products at the US national level. They represent a downward sloping demand curve for future wood products, assuming all stands are subjected to perpetual even-aged management. The variables have an objective function term (**ft**) reflecting the area underneath the terminal demand equation. They withdraw one unit from the terminal wood product balance. Within the GAMS implementation these variables are cases within ***FORWDDEMAND***.

The equations portrayed in table 5-1 that are associated with the forest sector are:

- Welfare -- Adds forest related net present value of consumers' and producers' surplus. The positive terms involve the area under the wood product demand curves for domestic consumption (**fd**), exports (**fe**), and terminal products (**ft**). The negative terms are of two different fundamental types. The first involves the area underneath explicit upward sloping supply curves for non-wood inputs (**fnw**) and wood products imports (**fi**). The second involves fixed per unit costs times quantities for stand production costs (**pc**), domestic transport (**fdt**), and public (Canadian) log supply (**fds**). Discounting provisions are included, as the model variables falling into the objective function embody a time dimension and consequently introduce income and cost streams arising in different time periods. Thus, they must be transformed into a common unit that we select to be year 2002 dollars. To do this FASOMGHG incorporates two different discounting procedures. First, because all variables give the annual activity levels during each five year period, their objective function terms are transformed to give the present value of period spanning constant activity at that rate. That involves multiplying the term by a factor, where the factor used is present value of a five year annuity for all but the terminal period, where a perpetual annuity factor is used. Second, the terms for time periods beginning in year t are multiplied by the discount rate for year t relative to year 2000. The objective function is the GAMS implementation equation ***WELFAR***.
- Exist timberland – All acres in the initial inventory (preexisting stands) must be allocated to some form of management or reserved class. The stands are defined by region, land class in terms of suitability for agriculture, site quality, stand type (softwoods,

hardwoods, planted pine, etc.), owner type (industrial or nonindustrial private), stand age, and management (including possible fertilization, partial cut and thinning regimes). This row depicts the GAMS implementation equation ***FORINVENTORYA***.

- Bare forest land -- Balances clearcut timberland with its use of timberland for reforestation, transfer to agriculture, and transfer to developed use (**fdev**). The stands are defined by region, land class in terms of suitability for agriculture, site quality, type of eligible succeeding forest stand, and forest owner (industrial or nonindustrial private). Clearcut acreage comes from existing stands, previously reforested stands and previously afforested stands but only after their first afforested rotation. This row depicts the GAMS implementation equation ***FORLANDBALANCE***.
- Bare land from ag -- Balances agricultural land transferring into forestry with its use for afforestation. The stands are defined by region, land classes suitable for agriculture, and site quality (high, medium). This equation only treats afforested stands during their first rotation. Subsequent stands go into the bare forest land balance. This row depicts the GAMS implementation equation ***FORAFFORLANDBALANCE***.
- Harvested log bal -- Balances the harvested logs from private and public sources with their use in wood products manufacturing. The private logs come from existing stands (**fhe**), reforested stands (**fhr**), or afforested stands (**fha**). They include logs obtained from clearcut harvests, thinning, and partial cuts. Public logs come from exogenous US public lands cut (**usps**) and from the *Endog public supply (Canada)* variable that depicts upward sloping supply of Canadian logs. Wood products manufacturing uses logs at the rate **fpu.** These equations are defined by region, log type, and time period. This row depicts the GAMS implementation equations ***FORBALEXHRV*** (which covers clearcuts of existing stands)**, *FORBALEXHPC*** (which covers thinning and partial cuts of existing stands)**, *FORBALNEWHRV*** (which covers clearcuts of reforested and afforested stands)**,** and ***FORBALNEWHPC*** (which covers thinning and partial cuts of reforested and afforested stands). The GAMS implementation equation ***FORWDBALANCE*** for log commodities is also involved.
- Min hardwoods -- Requires the standing hardwood area by owner to be greater than or equal to a minimum owner-specific acreage level (**mh**). The constraint is defined by region, type of forest owner, and time period. The GAMS implementation equation ***FORHARDWOODMIN*** is represented by this tableau row.
- For production cost -- Balances the use of pre-harvest forest production cost items with their supply. The costs arise under management of existing (**fce**), reforested (**fcr**), and afforested (**fca**) stands. The equation is defined by log producing region and time period. This row depicts the GAMS implementation equation ***FORCOSTBAL***.
- Wood products bal -- Balances manufactured wood product supply and demand. These equations are defined by region, wood product (including logs), and time period. Supply

is obtained from wood products manufacturing at the rate of **p** plus incoming domestic transport and imports. The demand arises from intermediate product use by manufacturing (at a rate also depicted by **p**), and outgoing transport plus domestic demand and exogenous exports (**exp**). Finally, there are adjustments for commodity movements to and from agriculture. This row depicts the GAMS implementation equation ***FORWDBALANCE.***

- For process capacity -- Imposes capacity limits on wood product manufacture. The capacity (**fcap**) is defined by time period, region, process, and wood product manufactured. This row depicts the GAMS implementation equations ***FORWDCAPACITY.***
- Mill residues bal -- Balances milling residue supply and demand. These equations are defined by region, residue type, and time period. Milling residues are obtained from wood products manufacturing at the rate of **m**. Demand arises from intermediate product use by manufacturing (at a rate also depicted by **m**). This row depicts the GAMS implementation equations ***FORWDRESBAL.***
- Non-wood input bal -- Balances wood product manufacturing activity with non-wood input supply. Non-wood input supply is from an upward sloping supply curve. The equation is defined by wood product, processing alternative, region, and time period. This row depicts the GAMS implementation equation ***FORWDNWCEQ.***
- Terminal for inventory -- Balances logs in terminal forest stands (those that persist beyond the explicit model time period) with their use in terminal wood products manufacturing. These logs come from private lands that are either in existing stands (**te**), reforested stands (**tr**), or afforested stands (**ta**). Wood products manufacturing uses logs at the rate **fpu.** These equations are defined by region, log type, and time period. This row is in the GAMS implementation equation ***FORBALEXHRV.***
- Terminal for prods -- Balances the terminal period supply and demand for manufactured wood products. Supply arises from wood products manufacturing at the rate of **p** plus incoming domestic transport and imports. Demand arises from intermediate product use by manufacturing (at a rate also depicted by **p**), outgoing transport, domestic demand, and exports. These equations are defined by region and wood product. This row depicts the GAMS implementation equation ***FORWDBALANCE.***
- GHG balance -- Balances net GHG emissions by type of GHG account with the GHG payments variable. The equations incorporate terms that reflect sequestration in forests and wood products along with GHG emissions from fossil fuel use. The term **ce** reflects the GHG emissions and sequestration associated with the management of existing forests, while **cr** reflects that from reforestation and **ca** that from afforestation. The term **cm** reflects carbon sequestered in wood products. GHG terms are also included, reflecting

effects for agriculture and land use change as discussed elsewhere. This row depicts the GAMS implementation equation ***GHGACCOUNTS***.

5.1.2 Agricultural sector submodel

The agricultural sector submodel depicts crop and livestock production, processing, feed blending, factor supply, consumption, interregional transport, and international trade. This submodel is represented by the tableau columns *Initial tillage* through *Domestic ag transport.* The agricultural submodel incorporates constraints on crop and pasture land; factor supply; supply/demand balances for crop, livestock, processed and blended feed products; and crop/livestock mixes. This is represented by the tableau rows *Crop land* through *Livestock mix.* The agricultural submodel also affects the GHG balance, as shown in the last tableau row. Next, we discuss each variable (column) depicted in the tableau along with each equation (row).

The variables in Tableau 5-1 that make up the agricultural sector submodel are:

- Initial tillage -- Assigns initial crop land assignment to the existing inventory. The variables are defined by region, tillage system (conventional, minimum till, and no till), irrigation status (irrigated or dryland), and crop land quality type. The variables use land from the initial tillage balance and supply it for cropped use. They also enter the GHG balances (**ts**) during each subsequent period, reflecting the trajectory of soil sequestration**.** Within the GAMS implementation these are the variables ***AGINITIALTILL***.
- Change tillage -- Tillage system and irrigation status alterations. The variables are defined by region, beginning and ending tillage system (conventional, minimum till and no till), beginning and ending irrigation status (irrigated or dryland), and crop land quality type. These variables use land from the balance of land eligible to change tillage, including land crossing over from forestry (that is placed in as conventional dryland) and, in turn, supply it for cropping under a particular tillage system and irrigation status, while permitting it to change again in a later time period. They also enter the GHG balance (**tcs**) during the current and future periods, reflecting the trajectory of changes in soil sequestration**.** Within the GAMS implementation these are the variables ***AGCHANGETILL***.
- Produce crops -- Agricultural crop production alternatives. The variable gives acres harvested in a time period by crop, irrigation status (irrigated or dryland), tillage method (conventional, minimum tillage, and no till), and degree of fertilization (base level, 15% reduction, or 30% reduction). The land on which the crops are planted is differentiated by region and crop land quality type. The variables reflect: (a) usage of fixed price inputs (**acc**) in the objective function, (b) usage of an acre of tilled land, (c) yield of crop commodities (**cy)**, (d) usage of labor and water (**cl**), and (e) a requirement for authorized

acreage from the crop mix. They enter the GHG balances (**ce**) reflecting net emissions involved with crop production, including those from fossil fuel and fertilizer use**.** Within the GAMS implementation these are the variables ***AGCROPBUDGET***.

- Produce livestock -- Livestock production alternatives. The variable gives the number of head by animal type, enteric fermentation alternative, and manure management alternative by region and time period. They reflect: (a) usage of fixed price inputs in the objective function (**alc**); (b) usage of pasture land (**pu**); (c) use of crop commodities for feed (**cu**); (d) livestock commodity yield (e.g., of milk) and intermediate product usage (e.g., calves used in feeding) at the rate **ly** per head; (e) agricultural processed commodity usage (**su**); (g) blended feeds usage (**fu**); (h) labor and AUM grazing usage (**ll)**; and (i) a requirement for authorized animals from the livestock mix. They enter the GHG balance reflecting net emissions (**le**), including those from fossil fuel, enteric fermentation, and manure. Manure management alternatives are incorporated in an associated variable. Within the GAMS implementation these are the variables ***AGLVSTBUDGET*** and ***AGLVSTMANURE***.
- Agricultural processing -- Agricultural processing alternatives. They give the volume of agricultural processing manufacturing activity. The variable is differentiated by processing alternative, region, and time period. Some of the processing alternatives are only defined at the national level. The variables reflect: (a) usage of fixed price inputs in the objective function (**apc**); (b) usage of crop commodities (**pc)**; (c) usage of livestock commodities (**pl**,); and (d) agricultural processed commodity production along with intermediate product usage (**py**). They enter the GHG balance (**pg**) reflecting emissions from fossil fuel usage and biofuel offsets**.** Within the GAMS implementation these are cases within the variables ***AGPROCESS*** and ***AGREGPROCESS***.
- Blend feed -- Feed blending alternatives. The variable involves determination of the number of units of blended feed manufactured by blending alternative. The variable is differentiated by feed type, blending alternative, region, and time period. The variables reflect: (a) fixed price input usage (**afc**) in the objective function; (b) crop commodity usage (**fc**); and (c) processed commodity usage (**fs**). Within the GAMS implementation these are cases within the variable ***AGREGPROCESS***.
- Sup water, AUMs, Labor -- Agricultural factor supply of water, labor, and AUM grazing. They give the amount supplied from fixed price and upward sloping supply curve portions. For water, this involves fixed price government owned, but leased, sources and an upward sloping supply curve for pumped, private, surface and ground water. For labor, this includes fixed price family and upward sloping hired labor supply. For AUM grazing, this includes fixed price AUMs available through grazing fees and AUMs available in an upward sloping fashion through private markets. The variable is differentiated by resource, type of source, region, and time period. The variables reflect: (a) the per unit fixed price or area underneath the supply curve relevant to the quantity of

the factors supplied in the objective function (**afs)**; and (b) supply into the resource usage balance row. Within the GAMS implementation these are cases within the variable ***AGRESSUPPLY***.

- Crop/pasture exchange -- Transformation of crop land to and from pasture or grasslands. The variable gives acres transformed in each direction by region and time period. The variables reflect: (a) per acre fixed cost of transformation in the objective function(**al)**; (b) supply or usage of crop land from the tilled land and can change tillage balances and (c) supply or usage of pasture land. These variables also enter the GHG balance, giving the trajectory of change in soil sequestration (**ds**), which is positive or negative depending on the direction of land use change. Within the GAMS implementation these are cases within the variable ***AGPASTLNDUSECHG***.
- Crop/livestock mix -- Choice among historically observed distributions within regions and livestock mix distributions across regions. The variable involves determination of the number of acres or head authorized within each observed mix. The crop mix variable is differentiated by region, historical alternative, and time period. The livestock mix variable is differentiated by historical alternative and time period. The variables reflect: (a) the share of the acreage of each crop in the total mix per unit of the alternative (**cm**); and (b) the share of the livestock herd by region in total mix per unit of the alternative (**lm**). Within the GAMS implementation these are the variables ***AGMIXR*** and ***AGNATMIX***.
- Ag export -- Agricultural commodity exports. Two cases are defined. For commodities with explicit spatial trade modeling, the variable is differentiated by time period, commodity, and consuming country. In that case, associated transportation variables are also defined. Other commodities are defined only with a total excess demand equation facing the US and involve time period and commodity. Crop, livestock, and processed commodities can be exported. The variables reflect: (a) the area underneath the demand curve (**ae**) in the objective function; (b) transport costs when explicit trade is being modeled are also within **ae**; and (c) usage of the associated crop, livestock, or processed commodity. Within the GAMS implementation these are cases within the variables ***AGDEMAND*** and ***AGTRADE***.
- Ag import -- Agricultural commodities imported. Two cases are defined. For commodities with explicit spatial trade modeling, the variable is differentiated by time period, commodity, and producing country. In that case, associated transportation variables are also defined. Other commodities are defined only with a total excess supply equation facing the US and involve time period and commodity. Crop, livestock, and processed commodities can be imported. The variables reflect: (a) the area underneath the supply curve (**ai**) in the objective function; (b) transport costs when explicit trade is being modeled are also within **ai**; and (c) supply of the associated crop, livestock, or processed

commodity. Within the GAMS implementation these are cases within the variables ***AGSUPPLY*** and ***AGTRADE***.

- Ag domestic consumption -- Domestic consumption of agricultural commodities above and beyond those consumed as feed and as intermediate inputs to processing. The variable is differentiated by time period and commodity. Crop, livestock, and processed commodities can be consumed. The variables reflect: (a) the area underneath the demand curve (**ad**) in the objective function; and (b) usage of the associated crop, livestock, or processed commodity. Within the GAMS implementation these are cases within the variables ***AGDEMAND***.
- Domestic ag transport -- Transport of agricultural commodities. Movements are depicted between domestic regions or from domestic regions to the national market. The variable is differentiated by time period, commodity, region of origin, and region of destination including a national destination. Crop, livestock, and processed commodities can be moved. The variables reflect: (a) the cost of transport (**adt**) in the objective function; (b) the historic price differences between region and national markets (**adt**); and **(c)** usage in the region of origin and supply in the region of destination. Within the GAMS implementation these are cases within ***AGTRADE*** and ***AGTRANSPRIM***.

Because of space limitations, some of the agriculturally related FASOMGHG variables were not portrayed. This includes the usage of idle pasture/grasslands and the associated sequestration in the GAMS implementation variables ***AGIDLELANDPASTURE*** and ***AGUSEPASTURE.*** There is also weak portrayal of the international trade variables ***AGTRADE,*** the movement to national market variables ***AGTRANSPRIM,*** and the manure treatment variables ***AGLVSTMANURE.*** More on these variables appears within the agricultural model chapter below.

The equations in Tableau 5-1 that make up the agricultural sector submodel are:

- Welfare -- Adds agriculturally related net present value of consumers' and producers' surplus. The positive terms involve the area underneath the agricultural products demand curves (**ad**), and the area underneath the agricultural products export demand curves (**ae**). The negative terms components of total cost. They include the area underneath explicit upward sloping supply curves, which involves the area under the upward sloping factor supply curves (***afs***) that depict the supply of water, AUMs, and labor, and the area underneath the agricultural product import curves (**ai**). They also include the fixed price times quantity for costs of inputs used in crop production (**acc**), livestock production (***alc)***, agricultural processing (***apc***), feed blending (***afc***), pasture to crop land transformations (***ale)***, and agricultural domestic transportation (***adt)***. Discounting provisions are also required. The model variables falling into the objective function embody a time dimension and consequently introduce income and cost streams arising in different time periods. Thus, they must be transformed into a common unit, which we select to be year 2000 dollars. To do this, FASOMGHG incorporates two different discounting procedures. First, because all variables give the annual activity levels during each five year period, their objective function terms are transformed to give the present value of period spanning constant activity at that rate. That involves multiplying the term by a factor where the factor used is present value of a five year annuity for all but the final explicit period, where a perpetual annuity factor is used. Second, the terms for time periods beginning in year t are multiplied by the discount rate for year t relative to year 2000. The objective function is the GAMS implementation equation ***WELFAR***.

- Crop land -- Limits the initial tillage allocation to the tillage inventory on hand. The land is defined by region, crop land quality, and tillage system employed (conventional, minimum tillage, no tillage). The tableau row has an exogenous land endowment (**cl**). This row depicts the GAMS implementation equations ***AGTILLSTART.***
- Land that can change till -- Limits possible tillage changes in the face of the current inventory of tilled land, adjusted for the net changes due to forestry/crop or crop/pasture land exchanges. The land is defined by region, crop land quality, tillage system employed (conventional, minimum tillage, no tillage), and irrigation status (irrigated or dryland). The tableau row reflects exogenous migration of agricultural land into developed uses (**cdev**). The left hand side entries depict land changing tillage systems, land moving in and out of forestry, land moving between crop and pasture land, and land exchanging between tillage systems. This row depicts the GAMS implementation equations ***AGCANCHANGETILL.***
- Tilled land -- Restricts use of crop land by tillage practice to the tillage inventory on hand by time period. The land is defined by region, crop land quality, tillage system employed (conventional, minimum tillage, no tillage), and irrigation status (irrigated or dryland). The entries depict the supply of tilled land from initial tillage, adjusted for tillage changes and land exchanges with forestry and pasture. This row depicts the GAMS implementation equations ***AGTILLUSE.***
- Pasture land -- Limits pasture land use to the pasture land inventory by time period and region. The entries depict the endowment of pasture (**pl**), adjusted for exchanges with forest and crop land. An exogenous adjustment of land flowing into developed uses is also present, but is not explicitly reflected in the tableau. Two pasture land related equations are present, one of which accounts for the pasture used and the other which balances total pasture including the possibility of idled pasture land. This permits accounting for sequestration on any idled pasture land. This row depicts the GAMS implementation equations ***AGPASTLANDEXCHANGE*** and ***AGLANDPASTURETILLUSE.***

- Crop balance -- Balances crop commodity supply and use. The equation contains US regional, US national, and foreign country balances by commodity and time period. The entries depict the yields from crop production (**cy**), direct feed use by livestock production (**cu**), usage in processing (**pc**), and usage in feed blending (**fc**). The equation also includes domestic consumption, exports, supply from imports, and adjustments for incoming and outgoing interregional transport. This row depicts cases within the GAMS implementation equation ***AGPRODBAL.***
- Livestock balance -- Balances livestock commodity supply and use. The equation contains US regional, US national, and conceivably foreign country balances by commodity and time period. The entries in the equation depict the yields of livestock from production (**ly**), direct use of some intermediate livestock categories like feeder pigs in livestock production (also depicted by **ly**), and usage in processing (**pl**). The equation also includes domestic consumption, exports, supply from imports, and adjustments for incoming and outgoing interregional transport. This row depicts cases within the GAMS implementation equations ***AGPRODBAL.***
- Processed ag commod -- Balances processed agricultural commodity supply and use. The equation contains US regional, US national, and conceivably foreign country balances by commodity and time period. The entries depict the usage of processed commodities as feeds by livestock production (**su**), supply of processed commodities from agricultural processing (**py**), direct use of some intermediate processed commodities like cornstarch in HFCS manufacture by processing alternatives (also depicted by **py**), and usage in feed blending (**fs**). The equation also includes domestic consumption, exports, supply from imports, and adjustments for incoming and outgoing interregional transport. Finally, there are adjustments for commodity movements to and from forestry. This row depicts cases within the GAMS implementation equation ***AGPRODBAL.***
- Feed balance -- Balances blended feed commodity supply and use. The equation contains US regional balances by blended feed commodity and time period. The entries in the equation depict the balance between usage of blended feed commodities by livestock production (**fu**) with the supply from the feed blending alternatives. This row depicts cases within the GAMS implementation equation ***AGPRODBAL.***
- Water, AUMs, labor balance -- Balances usage of irrigation water, AUM grazing, and labor supply with their supply. Usage comes from crop (**cl**) and livestock (**ll**) production. The nature of the factor supply terms differs by resource. For water, a homogenous commodity acre feet of irrigation water is supplied by either fixed price governmentally owned, but leased, water or an upward sloping supply curve for pumped, private, surface and ground water. For labor, the homogeneous commodity hours of labor is supplied by either fixed price family sources or an upward sloping hired labor supply curve. For AUM grazing, the homogeneous commodity of one animal unit of grazing is supplied by either fixed price AUMs available through grazing fees or an upward sloping supply

curve of AUMs available through private markets. The equation is differentiated by region, factor, and time period. This row depicts the GAMS implementation equations ***AGRESBALANCE.***

- Crop mix -- Balances acreage by crop in a region with the proportional occurrence of that crop in historically observed cropping patterns. The equation covers irrigation and dryland restictions for all crops that have been observed in crop mixes for the time periods. Generally, these constraints are defined within the first 20 years of the model run. The equations are present for aggregation purposes as discussed above. The equation balances the acres used in crop production possibilities with their supply from the crop mix alternatives (**cm**). Although not explicitly shown here, a convexity requirement is imposed that balances total acreage across all crops with the total acreage covered by the mixes. The equation is differentiated by region, crop, irrigation status, and time period. Simultaneously, a lower bound is imposed so that the acreage in the crop mix must be at least 90% of that in the historical mix. This row depicts the GAMS implementation equations ***AGCRPMIXUP*** and ***AGCRPMIXLO.***
- Livestock mix -- Balances regional head by animal type with the proportional occurrence across regions in the US in historically observed livestock population patterns. The equation is defined for time periods in the first 20 years of the model run. The equations are present for aggregation purposes as discussed earlier. The equation reflects the need for a livestock head by the livestock production possibilities and its supply from the livestock mix alternatives (**lm**). The equation is differentiated by region, animal type, and time period. This row depicts the GAMS implementation equations ***AGLIVESTOCKMIXNAT.***
- GHG balance -- Balances the GHGs by GHG account with GHG payments. These equations incorporate sequestration in soils, biofuel offsets, and emissions. The coefficients associated with crops involve sequestration associated with initial tillage (**ts**), tillage change (**tcs**), and land use change between crop land and pasture (**ds**). Sequestration accounting is also included within the term for changes in cropped acreage production (**ce**) when longer lived perennials are involved. Crop production related emissions are also included in the term **ce** and reflect emission's associated with:
    - Fossil fuels used in tillage, planting, harvesting, and other machinery operations
    - Crop drying
    - Irrigation
    - Histosoils
    - Nitrogen fertilization
    - Rice production
    - Fertilizer and pesticide manufacture
    - Residue burning

- Sewage sludge usage
- Nitrogen fixing crops.

Livestock related emissions associated with fossil fuel usage, enteric fermentation, and manure management are reflected in **le.** Emissions related to agricultural processing are reflected within **pg**. The coefficients **pg** also incorporate accounting for biofuel-related offsets when biofuel feedstocks are made into ethanol, diesel, or coal substitutes. GHG involvement from forestry operations and land use changes also appear. This row depicts the GAMS implementation equations ***GHGACCOUNTS***.

Although almost all of the FASOMGHG agriculturally related equations are shown in the tableau, there are a couple that are either not represented or are less than fully represented. This includes missing portrayals of equations imposing maximums on fixed price factor supplies (***AGRESMAX***), a manure related balance between livestock that can be managed with improved manure management systems and those treated by improved manure management systems (***AGMANUREMGT***), and a maximum transfer of pasture land to crop land ***AGMAXPASTURETOCROP***. In addition, there are also less than detailed portrayals of lower bounds on participation in crop mixes ***AGCRPMIXLO,*** foreign trade balances within the ***AGPRODBAL*** equation, pasture land in use and idle pasture land in ***AGPASTLANDEXCHANGE*** and ***AGLANDPASTURETILLUSE***. These cases are covered more extensively in the agricultural modeling chapter below.

5.1.3 Intersectoral transfer submodel

The intersectoral transfer submodel depicts movements of land and commodities between the forestry and agricultural sectors. This submodel is represented by the tableau columns labeled *Crop land from ag* through *Move ag to for commod.* The first four of these columns depict land transfers and the last two depict commodity transfers. Land transfers are limited by the equations *Max for land transfer* and *Max ag land transfer.* The explicit land balance or commodity balance rows are not treated within this submodel, rather the submodel variables have entries in the land availability and commodity balance equations within the forestry and agricultural sector submodels. Here we will first discuss the issue of land synchronization and then will turn attention to the tableau components.

5.1.3.1 Land definition synchronization

Before discussing the intersectoral transfer submodel features, it is important to discuss region and land type synchronization. Land in the forestry sector is defined at the 11 FASOMGHG region geographic level, with quality dimensions including land classes relevant for exchange with agriculture (***FORCROP, CROPFOR, FORPAST,*** and ***PASTFOR***) and three site productivity indices (***high, medium,*** and ***low***). On the agricultural side, the land base is defined on a 63 region basis in the first 20 modeled years and later on a FASOMGHG 11 region basis. In addition, while pasture land is defined as a single homogeneous commodity, crop land is not. Rather, crop land is differentiated into four crop land quality classes (***w3-8***, ***loei***, ***mdei***, and ***svei***) and is also differentiated by tillage practice employed and irrigation status.

To best model sequestration and control land movements, several assumptions are used to synchronize these disparate regional definitions. Briefly these assumptions are:

- When crop land moves into forestry, it falls into the ***FORCROP*** class with high site productivity.
- When pasture land moves into forestry, it falls into the ***FORPAST*** class with medium site productivity.
- When crop land moves out of forestry, it comes from either the ***FORCROP*** or ***CROPFOR*** classes with high site productivity.
- When pasture land moves out of forestry, it comes from either the ***FORPAST or PASTFOR*** classes with medium site productivity.
- When crop land moves between forest and agriculture, it exchanges with the crop land quality differentiated lands in proportion to the original incidence of those lands in the crop land endowment data. This means that if the land in a region initially is 33% ***w3-8*** and 67% ***mdei*** land, that the land moving in or out will be placed into or withdrawn from these two classes in the proportions 0.33 and 0.67.
- When crop or pasture land moves between one of the FASOMGHG 11 regions into the agricultural sector during the periods in which the agricultural sector is disaggregated into 63 subregions, that land moves into the subregions in proportion to the incidence in the initial distribution of subregional land. This procedures differs somewhat for crop and pasture land.
    - For pasture land, it moves in proportion to initial subregion shares of pasture land for subregions included in the larger regions. For example, suppose we consider land movements in the Pacific Southwest (PSW) region. Assume the initial endowment of land shows 20% of the PSW pasture land is in Southern California and 80% in Northern California. In that case, transferred pasture land would come from or be placed into the subregional pasture land balances at the rate of 0.2 acres in Southern California and 0.8 acres in Northern California.
    - The crop land case is more complex because it must also synchronize with the crop land quality dimension. Namely, because crop land is subdivided into four crop land quality classes, the land exchanges need to be distributed across the four crop land classes while simultaneously falling across the contained subregions. In

our PSW example above, there would be eight subregion/quality cases. In turn, the land is distributed into those eight cases according to their observed proportions in the initial crop land endowment data.

- When forest land exchanges with crop land, it always comes from or goes into the inventory of acres with dryland irrigation status that are conventionally tilled. The model can actually move land from or to other tillage/irrigation status cases by coupling the land transfer with a tillage change.
- Although this discussion is centered on land transferring at the FASOMGHG 11 region level, not all such transfers are allowed. Namely, land transfers only occur in regions that have both agricultural and forestry production. This is true for only eight of the FASOMGHG 11 regions.

Such procedures are not needed on the commodity side because the agricultural regional commodity model is always defined at the FASOMGHG 11 region level and the commodities can move on a one-to-one basis between comparable regions.

5.1.3.2 Tableau components

The variables in the intersectoral land transfer submodel are:

- Crop land from ag -- Afforestation of agricultural crop land. Such land movements are defined at the FASOMGHG 11 region level by time period. They remove land (**als**) from the agricultural tilled land and can change tillage land balances and place it into the forest land balance. They incur a cost of land transformation (**alt)** in the objective function. They are limited by an exogenous maximum transfer limit (**ac**). They remove sequestered carbon from the GHG balance category for agricultural sequestration (**as)** by zeroing out the agricultural component for this acre (note sequestration accounting is then picked up by the afforestation and later possibly by reforestation variables). In turn, these movements are equated with a set of variables that move the transferring land into the FORCROP class with a HIGH site productivity classification into any of the possible types of succeeding forests. This tableau column represents cases within the GAMS implementation variables ***LANDFROMAG*** and ***CONVRTFROMAG***.
- Pasture land from ag -- Afforestation of agricultural pasture land. Such land movements are defined at the FASOMGHG 11 region level by time period. They remove land from the agricultural pasture land balances (**als**) and place it into the forest balance. They incur a cost of land transformation (**alt)** in the objective function. They are limited by an exogenous maximum transfer limit (**ac**). They remove sequestered carbon from the GHG balance (**as**) **by** zeroing out the agricultural component for this acre (note sequestration accounting is then picked up by the afforestation and later reforestation variables). In turn, these movements are equated with a set of variables that move the transferring land

into the FORPAST class with a MEDIUM site productivity classification for any of the possible types of succeeding forests. This tableau column represents cases within the GAMS implementation variables ***LANDFROMAG*** and ***CONVRTFROMAG***.

- Land to ag crop land -- Deforestation and land use change to agricultural cropping. Such land movements are defined at the FASOMGHG 11 region level by time period from the CROPFOR or FORCROP classes with a HIGH site productivity classification. They remove land from the forestry balance and subsequently place it into the agricultural Tilled land class, and land can change tillage balances at the rate **als**. They incur a cost of land transformation (**flt)** in the objective function. They are limited by an exogenous maximum transfer limit (**ac**) and add sequestered carbon to the GHG balance category for agricultural sequestration (**as).** This starts up the agricultural sequestration accounting for this acre (note sequestration accounting is dropped by the forestry component in the period before timber harvest). This tableau column represents cases within the GAMS implementation variables ***LANDTOAG*** and ***CONVRTTOAG***.
- Land to ag pasture -- Deforestation and land use change into agricultural pasture. Such land movements are defined at the FASOMGHG 11 region level by time period from the PASTFOR or FORPAST classes with a MEDIUM site productivity classification. They remove land from the forestry balance and place it into the agricultural pasture land balances at the rate **als**. They incur a cost of land transformation (**flt)** in the objective function. They are limited by an exogenous maximum transfer limit (**ac**). They remove sequestered carbon from forestry sequestration GHG balance at the rate **as,** starting up the agricultural sequestration component for this acre (note sequestration accounting is dropped by the forestry component in the period before timber harvest). This tableau column represents cases within the GAMS implementation variables ***LANDTOAG*** and ***CONVRTTOAG***.
- Move for to ag commod -- Movement of processed forestry commodities into the agricultural processed commodity balances. Commodity movements are defined at the FASOMGHG 11 region level by time period. They involve forestry commodities that are suitable as biofuel feedstocks. They incur cost of movement in the objective function at the rate **acm**. They remove commodities from the wood product balances at the rate **fm** and place them into the agricultural commodity balances at the rate **am**. This tableau column represents cases within the GAMS implementation variables ***MOVCOMTOAG.***
- Forest commodities moved from ag -- Movement of processed agricultural commodities into the wood product balances. Such commodity movements are defined at the FASOMGHG 11 region level by time period. They involve agricultural commodities that are suitable fiber resources for pulp and paper manufacturing processes. They incur cost of movement in the objective function at the rate **fcm**. They remove commodities from the agricultural commodity balances at the rate **am** and place them in the wood products

balance at the rate **fm**. This tableau column represents cases within the GAMS implementation variables ***MOVCOMFROMAG.***

The equations in the tableau that are related to the intersectoral transfers are the sectoral specific balances as discussed in the forestry and agricultural sections above, along with the following two equations:

- Max for land transfer -- Limit the maximum amount of forest land that can be transferred to agriculture and also defines adherence to cost function steps depicting increasing costs of land transformations as more land is transferred. They are defined by region for a total amount of land that could transfer across all time periods (**ltf**), with accounting in all subsequent time period so that it reflects the effects of past land transfers. This tableau row represents the GAMS implementation equations ***MAX_FOR_TO_AG_LAND*** and ***FOR_TO_AG_LANDTRNLIM***.
- Max ag land transfer -- Limit the maximum amount of agricultural land that can be transferred to forestry. They are defined by region for a total amount of land that could transfer across all time periods (**lta**), with an accounting in each subsequent time period so that it reflects the effects of past land transfers. This tableau row represents the GAMS implementation equations ***AG_TO_FOR_LANDTRNLIM***.

In the interests of space, the tableau does not portray the FASOMGHG equations that equate the variables ***LANDTOAG*** and ***LANDFROMAG*** that represent the land moving into and out of agriculture that are not differentiated by class, site productivity class, or type of possible forest successor with a set of the variables that do have such designations (***CONVRTTOAG, CONVRTFROMAG***). This involves the GAMS implementation equations ***TRNTOLDBAL*** and ***TRNFRLDBAL.***

5.1.4 GHG submodel

The GHG submodel accounts for and reflects payments to net GHG emission reductions above those in the baseline from agriculture and forestry, including sequestration activity, emission activity, and biofuel related offset activity. In the tableau, the GHG submodel is represented by the column *GHG payment* and the row *GHG balance*. The *GHG balance* row depicts the involvement of agricultural and forestry activities. In turn, given a policy or GHG price signal, these submodels can employ different production possibilities to reduce net emissions.

5.1.4.1 GHG payment variable

The GHG payment variable reflects the cumulative amount of sequestration, emissions, or biofuel generated offsets by time period for each GHG account named above. This variable can be either positive or negative and is equated with the quantity computed by the account specific GHG balance equations. The variable has an objective function coefficient that reflects the pricing of changes in this GHG account as portrayed by the term **gp**. This objective function term is somewhat complex, encompassing several different factors. Specifically it involves:

- Computation of the net gain in the GHG account accrued since the last time period that is above and beyond the net gain in the baseline. This is done by incorporating the difference between the GHG payment variable in the current period and the variable value in the last period ($GHGpayment_t$ - $GHGpayment_{t-1}$) to get the gain. Then we subtract off the difference in gain observed in a baseline by subtracting the baseline number for this period minus the baseline for the previous period ($baseline_t$ - $baseline_{t-1}$).
- Conversion of all accounts to a carbon dioxide equivalent basis by multiplying by the appropriate GWP.
- Attaching the proper signs to emissions, offsets, and sequestration, specifically a negative sign to emissions and a positive to offsets and sequestration. This gets everything to the point that increases in the account would earn a positive payment.
- Multiplying the individual account terms times a zero-one indicator that tells whether the GHG account is eligible for GHG payments from a policy standpoint.
- Introducing discounting provisions to convert all dollar flows to a year 2000 net present value. This involves two stages. First, we multiply by an annuity factor that alters typical payments in each five year period to the net present value of total payments for that period. Then we multiply by a discount factor that reduces the value back to year 2000 dollars. The annuity factor used is the value of a five year annuity for all time periods but the last explicit one in the model. In that period, the factor for present value of an infinite annuity is used, assuming that activity persists forever as is discussed under the topic of the integrating objective function just below.

5.1.4.2 GHG balance equation

The tableau row showing the GHG balance equation portrays the way the equation balances net GHG emissions by type of account with net GHG payments. These equations encompass GHG sequestration, emissions, and biofuel related offsets. The tableau portrayal for this equation is rather simplistic but within FASOMGHG it covers many different cases and mitigation options. Let us review these by submodel.

- In the terms associated with the forestry submodel, the equations reflect sequestration in forest soils, ecosystems, and standing trees, along with sequestration in wood products and emissions from production related to fossil fuel use. The term **ce** reflects the GHG emissions and sequestration associated with the management of existing forests, while **cr** reflects that for reforested lands and **ca** for afforested lands. The term **cm** reflects carbon sequestered in wood products.

- In the terms associated with the agricultural submodel, these equations incorporate effects on soil sequestration, biofuel offsets, and emissions. The coefficients associated with crops involve sequestration associated with initial tillage (**ts**), tillage change (**tcs**), and land use change between crop land and pasture (**ds**). Sequestration accounting is also included within the term for changes in cropped acreage production (**ce**) when longer lived perennials are involved. Crop production related emissions are also in the term **ce** and reflect emission's associated with:
  - Fossil fuels used in tillage, planting, harvesting, and other machinery operations
  - Crop drying
  - Irrigation
  - Histosoils
  - Nitrogen fertilization
  - Rice production
  - Fertilizer and pesticide manufacture
  - Residue burning
  - Sewage sludge usage
  - Nitrogen fixing crops.

  Livestock related emissions associated with fossil fuel usage, enteric fermentation, and manure management are reflected in **le.** Emissions related to agricultural processing are reflected within **pg**. The coefficients **pg** also incorporate accounting for biofuel related offsets when biofuel feedstocks are made into ethanol, diesel, or coal substitutes.
- In the intersectoral transfer part of the model, the coefficients **ts** reflect the amount of the carbon sequestration that is withdrawn from accounting in the agricultural sector when land moves from agriculture into forestry (where soil carbon accounting is then picked up within a forestry account). Likewise, these coefficients reflect the amount of sequestration that is added into the agricultural soil carbon accounting when land moves from the forest sector and is thus dropped from the forest sector soil accounting.

This row depicts the GAMS implementation equations ***GHGACCOUNTS***.

5.1.4.3 GHG mitigation alternatives portrayed

Within these equations, there are numerous management alternatives to reduce net GHG emissions below baseline levels. These are referred to throughout the document as mitigation options and include forestry, agricultural, and biofuels options.

Forestry mitigation options include:

- Management manipulations in the form of lengthened timber rotations or altered forest species choice.
- Expanded usage of more intensive (higher input) management.
- Expansions in forested area through conversion of agricultural lands into forest uses (afforestation).
- Avoiding conversion of forested areas to agriculture (avoided deforestation).
- Conversion of harvested wood into longer-lived wood products.
- Utilization of techniques that embody less fossil fuel usage.
- Usage of harvested wood to offset fossil fuel usage, employing it in electrical generation or other forms of biofuels.
- Choice of management by region and site to introduce or manipulate forests on highly productive fast-growing sites to obtain higher timber yields and faster rates of carbon sequestration.

Agricultural mitigation options include sequestration and emission management possibilities, where the sequestration ones include:

- Deintensifying agricultural tillage.
- Increasing the relative abundance of grasslands.
- Altering the mix of annuals versus perennials, increasing the standing biomass through crop mix choice or crop management.

While the agricultural emissions related ones include:

- Lowering fossil fuel usage.
- Lowering chemical usage, saving the GHG emissions obtained in producing them.
- Reducing fertilization rates.
- Manipulating enteric fermentation by altering ruminant livestock feeding and rate of gain.
- Improving manure management.
- Reducing the size of the livestock herd.
- Lessening rice acreage.
- Reducing legume acreage.
- Manipulating crop mix, irrigated/ dryland use, regional, and soil type locations of crops.
- Manipulating regional size and composition of the livestock herd, feed blend employed.
- Manipulating consumption patterns, processing patterns, and import/export mixes.

Biofuels feedstock related options involve agriculture and forestry provision of feedstocks that are in turn used to produce:

- Ethanol as a replacement for gasoline through the conversion of corn, sugar cane, switchgrass, poplar, and willow.
- Electricity through use of milling residues, harvested wood, switchgrass, poplar, and/or willow as feedstocks as a substitute for coal.
- Biodiesel from soybeans or corn, for use in transportation fuel.

5.1.4.4 Other GHG related features

A few clarifying comments are also in order on the nature of the way that FASOMGHG handles the GHG parts of the model:

- An exogenously specified trajectory for GHG prices (expressed in carbon equivalents) is specified by five year period. Note that although this input can reflect increasing GHG prices over time, the model has perfect foresight and thus rising prices can alter current economic behavior in complex ways.
- Incentive payments are not paid for the total stock of GHG emissions, offsets, or sequestration, but rather for deviations from the baseline.
- FASOMGHG is initially run with a zero carbon equivalent price that is taken as the business-as-usual baseline.
- Provisions are made to allow the user to include discounts on a national basis for any of the GHG accounts. These discounts are for permanence, leakage, additionality, and uncertainty. Each of these potential discount factors has a default value of zero.

5.1.5 Integrating objective function

The integrating objective function computes total consumers' and producers' surplus across all four submodels and is maximized in the FASOMGHG solution. The objective function is shown in the tableau row labeled *Welfare*. In this equation, we see positive contributions to welfare arising in association with:

- Area underneath the domestic demand curves for forestry (**fd**) and agricultural (**ad**) products.
- Area underneath the export demand curves for agricultural (**ae**) products.
- Valuation of terminal forest inventory (**ft**).
- GHG payments to net emissions reductions (**gp**).

In turn, total cost is subtracted in the form of areas underneath supply curves and price times quantity for fixed price cost items. The area under the explicit upward sloping supply functions includes:

- Endogenous (Canadian) log supply
- Forestry non-wood inputs (**fnw**).
- Agricultural (**ai**) and forestry imports (**fi**).
- Agricultural factor supplies for water, AUMs, and labor (**afs**).

The total cost of the fixed price inputs, which is subtracted by taking price times quantity, is computed for:

- Stand production (forest management) costs (**pc**).
- Costs of domestic wood product transport (**fdt**).
- Public log supply (**fds**).
- Costs of land transformations from agriculture to forestry (**alt**).
- Costs of land transformations from forest to agriculture (**flt**).
- Costs of commodity movements from forest to agriculture (**fcm**).
- Costs of commodity movements from agriculture to forestry (**acm**).
- Costs of inputs used in crop production (**acc**).
- Costs of inputs used in livestock production (**alc**).
- Costs of inputs used in agricultural processing (**apc**).
- Costs of inputs used in feed blending (**afc**).
- Costs of land transformations between pasture and crop land (**ale**).
- Agricultural domestic transportation costs (**adt**).

Discounting provisions are also included. The model variables falling into the objective function embody a time dimension and consequently introduce income and cost streams arising in different time periods. Thus, they must be transformed into a common unit which we select to be year 2000 dollars. To do this, FASOMGHG incorporates two different discounting procedures. First, because all variables give the annual activity levels during each five year period, their objective function terms are transformed to give the present value of period spanning constant activity at that rate. That involves multiplying the term by a factor where the factor used is present value of a five year annuity for all but the terminal period in forestry and the last explicit period for agriculture and GHG payments. In those periods, a perpetual annuity factor is used. Second, the terms for time periods beginning in year t are multiplied by the discount rate for year t relative to year 2000. The objective function is the GAMS implementation equation ***WELFAR***.

5.2 Aggregate spatial portrayal

The tableau in table 5-1 portrays virtually the whole structure of the FASOMGHG programming model. However, because of a desire that it fit on a single page, it was constructed to represent a single aggregate region and a single aggregate time period. A companion tableau that reveals some regional details is shown in table 5-2. However, this again requires compromise to fit it on a single page. As consequence, we portray a two-region model but in the process need to aggregate or drop much of the forestry and agricultural sector submodel detail. Note this tableau omits many features in FASOMGHG and is designed to showcase the regional dimension.

The variables in this tableau are

- Reg forest production -- Acres of forest production across alternatives and inventories by region. This variable portrays forest production form existing, reforested, and afforested stands (the first three columns in table 5-1). The tableau shows that the regional forest production variable draws from the regionally specific timberland inventories while producing regional harvested logs (**fh**) and entering the national GHG balance to reflect sequestration and fossil fuel related emissions (**fc**).
- Reg Manufacture wood -- Regionally specific wood products manufacturing activity. This column is a regionally enhanced depiction of the *Manufacture wood prods* column in table 5-1. This variable uses harvested logs from a regionally specific harvested log balance at the rate **fpu,** while producing goods into the regionalized wood products balance at the rate **p** and, if specified, using regional wood products as intermediate products to the production process (also part of **p**). It also requires the supply of non-wood inputs from the regional and process specific non-wood input balance. Finally, it enters the national GHG balance reflecting the fate of sequestered carbon in wood products at the rate **cm**.
- Reg En. Public supply -- Supply of logs from regional public land harvesting (in Canada only). This column is a regionally enhanced depiction of the *Endog public supply (Canada)* column in table 5-1. This variable supplies harvested logs into the regional harvested log balance, while incurring a cost (**fds**) in the objective function.
- Reg non-wood inputs -- Supply of non-wood input items as inputs into wood products manufacturing. These items are defined by region, process, and wood product. The non-wood input supply involves an upward sloping supply curve to reflect increasing regional costs of wood product manufacturing as the quantity manufactured increases. This column is a regionally enhanced depiction of the *Non-wood inputs* column in table 5-1. The non-wood input items are placed into a non-wood balance equation that reflects

regional processes and is product specific. The associated objective function term (**fnw**) gives the area underneath the non-wood input supply equation.

- Reg wood products trade -- International imports and exports of manufactured wood products. This variable adds one unit of manufactured wood product into the regional balance when importing and withdraws one unit when exporting. It has an associated objective function cost term that adds the area under the regional and wood product specific export demand curve when exporting or subtracts the area under the regional and wood product specific import supply curve when importing. This column is an aggregation of the columns *Forest import* and *Forest export* in table 5-1 but also elaborates on their regional dimension, showing that they are defined in association with forest regions and not the national market.
- Reg for com to nation -- Movements of manufactured wood products into the national market. This preserves model adherence with the law of one price. It withdraws one unit of a manufactured wood product from the regional balance and then enters it into the national wood product balance. This movement has an associated objective function cost term (**fpd**), which is the typical price difference between regional and national prices. This column is an elaboration on the column *Forest domestic transport* in table 5-1 and is one of the subcases contained within the GAMS implementation variable ***FORWDTRANSPORT***.
- Wood reg to reg -- Interregional movements of manufactured wood products. This variable withdraws one unit of a manufactured wood product from the originating region and then enters it into the destination region. In this movement, an interregional transport cost (**fdt**) is incurred in the objective function. This column is an elaboration on *Forest domestic transport* in table 5-1 and is contained within the GAMS implementation variable ***FORWDTRANSPORT***.
- Wood product demand -- National demand for manufactured wood products that involves a downward sloping demand curve. This variable withdraws one unit from the national wood product balance. It also reflects the area underneath the wood products demand curve (**fd**) in the objective function. This column is another portrayal of the *Wood product demand* column from table 5-1.
- Reg Land from Ag -- Regional agricultural crop and pasture land moving into forestry for afforestation. This variable withdraws one unit of land from the regional agricultural land balance (possibly disaggregated by subregion and land quality class as discussed under the intersectoral transfer model above) and places it in the regional balance with the appropriate forest class. It also reflects the hurdle costs of land transformation (**alt**). This column is another portrayal of the columns *Crop land from ag* and *Pasture land from ag* in table 5-1.

- Reg Land to ag -- Regional forest land being deforested and moving into agriculture for use as crop or pasture land. This variable withdraws one unit of land from the forestry bare land balance and moves it into the agricultural land balance (possibly disaggregated by subregion and land quality class as discussed under the intersectoral transfer model above). It also reflects the costs of land transformation (**flt**) for stump removal and other land clearing activities. This column is another portrayal of the *Land to ag crop land* and *Land to ag Pasture land* columns in table 5-1.
- Reg Produce crop/live -- Crop and livestock production by region. This portrays the columns *Crop production* and *Livestock production* as well as the tillage related columns in table 5-1. The regional agricultural production variables draw from the regional agricultural land inventory (**alu**), while producing regionally differentiated crop (**ac**) and livestock (**alp**) commodities, possibly using some livestock as intermediate inputs (also within **alp**) and secondary/ blended feed commodities (**as**). It also uses water, AUMs, and labor (**af**). Finally, it enters the national GHG balance reflecting sequestration and emissions (**ag**).
- Reg Ag processing/blend -- Regional agricultural processing and feed blending. This portrays the columns *Agricultural processing* and *Feed blending* in table 5-1. Regional agricultural processing and feed blending draws from the regional agricultural crop (**pc**) and livestock (**pl**) balances, while producing regional processed commodities (**py**) and possibly uses some processed commodities as intermediate inputs (also within **py**). Finally, it enters the national GHG balance, reflecting sequestration and emissions (**pg**). Not all processing is regionalized and in those cases this variable appears in association with the national commodity balance.
- Reg water, AUMs Lab -- regional supply of water, AUMs, and labor. This column is a regionally enhanced depiction of the *Sup water, AUMs, labor* column in table 5-1. The factors are placed into regional and factor specific water, AUMs, and labor balance equations. An associated objective function term appears that gives the area underneath the upward sloping factor supply equation (**fds**).
- Reg Ag trade -- International imports and exports of the agricultural products that are modeled with spatially explicit trade. This variable adds one unit of imported product into the regional balance when importing and withdraws one unit when exporting. It has an associated objective function term (**s**) that adds the area under the foreign country specific export demand curve when exporting or subtracts area under the country specific import supply curve when importing. This column is an aggregation of the columns *Ag import* and *Ag export* in table 5-1. It also elaborates on their regional dimension. Although not explicitly shown here, international transport between regions and foreign countries is also involved.

- Reg Move ag to nation -- Movement of agricultural crop, livestock, and processed commodities into the national market. This preserves model adherence with the law of one price. This variable withdraws one unit of a commodity from the regional balance and then enters it into the national market balance. This movement has an objective function cost term (**fpd**) that is the typical price difference between regional and national prices. This is an elaboration on the column *Domestic ag transport* in table 5-1.
- Reg to reg ag transport -- Interregional movements of agricultural commodities. This variable withdraws one unit of a commodity from the originating region and then enters it into the destination region. This movement has an associated objective function transport cost term (**adt**). This column is an elaboration on the column *Domestic ag transport* in table 5-1.
- Ag domestic consumption -- National demand for agricultural products. It involves a downward sloping demand curve. This variable withdraws one unit from the national commodity balance. It also reflects the area underneath the demand curve (**ad**). This column is another portrayal of the column *Ag domestic consumption* in table 5-1.
- Ag trade -- International imports and exports of agricultural products that are modeled without spatially explicit trade. This variable adds one unit of the commodity into the national balance when importing and withdraws one unit when exporting. It has an objective function term (**s**) that adds the area under the rest of world excess demand curve when exporting or subtracts the area under the world excess import supply curve when importing. This column is an aggregation of the columns *Ag import* and *Ag export* in table 5-1.
- GHG payments -- GHG payments by GHG account. Another portrayal of the *GHG payment* column in table 5-1. The objective function term (**gp**) reflects payments for GHG fluxes above the baseline and withdraws from the GHG balance equation.

The equations in this tableau are:

- Welfare -- Adds up consumers' and producers' surplus across the total programming model. The terms are discussed in the definition of the *Welfare* row in table 5-1. The portrayal here shows that many of the included items are regionally specific.
- Reg Timberland -- Limits regional forest land use to land available. Regional lands can either come from the initial endowment (**fl**) or movements from agriculture. Land available is reduced by movements to agriculture. This equation aggregates several equations from table 5-1, encompassing *Exist timberland, Bare forest land,* and *Bare land from ag*.
- Reg Harvested Logs -- Limits use of regional harvested logs to harvested logs available. Available harvested logs can come from either harvests in regional private forests (**fh**) or from regional exogenous public supply. Harvested logs are used by the regionalized

wood products manufacturing variables. This row portrays the *Harvested log bal* row in table 5-1.

- Reg Wood Products -- Constrains regional use of manufactured wood products to the quantity available. Wood products are produced by regional wood products manufacturing (**p**) or can be imported. Regional wood products can be domestically transported, exported, or transferred to national demand. Wood products can also be used as intermediate products by manufacturing as also depicted by **p**. This portrays the *Wood products bal* row in table 5-1.
- Reg Non-wood input -- Balances regional supply of non-wood input items with their use by wood products manufacturing. This portrays the *Non-wood input bal* row in table 5-1.
- National wood products -- Balances national consumption of manufactured wood products with supply transferred in from the regions. This row establishes a national price that is translated to the regional prices, taking into account typical price differences. The row portrays the *Wood products bal* row in table 5-1.
- Reg Ag land -- Constrains regional agricultural land use (**alu**) to land available. Regional lands either come from the initial endowment (**cl**) or movements from forestry and are reduced by movements to forestry. This equation aggregates *Initial crop land, Land that can change still, Tilled land,* and *Pasture land* from table 5-1.
- Reg crop balance -- Constrains regional use of crop products to the quantity available. Available regional crops come from agricultural production (**ap**) or imports. Crop products are used by the regional agricultural processing and feed blending (**pc**) or can be exported. Regional crops can also be domestically transported, or transferred to the national demand. Crop products can be used directly as feeds by regional livestock as also depicted in **ap**. This tableau row portrays the *Crop balance* row in table 5-1.
- Reg livestock balance -- Limits regional livestock product use to availability. Livestock come from agricultural production (**alp**) or imports. Livestock products are used by regional processing (**pc**) or export. Also regional livestock can be domestically transported, transferred to the national demand, or used as intermediate products by other livestock production possibilities, as also depicted in **alp**. This portrays the *Livestock balance* row in table 5-1.
- Reg processed/feed -- Limits regional use of processed agricultural and blended feed products to the quantity available. Processed and blended feed products come from processing or feed blending (**pl**). Such products are used by the regional agricultural production at the rate **as** or can be moved to the national balance. These products can also be used as intermediate products by processing and feed blending possibilities as also depicted in **py**. This tableau row portrays an aggregation of the *Processed ag commod* and *feed balance* rows in table 5-1.

- Reg Wat, AUMs, Lab -- Balances regional supply of water, AUMs, and labor items with use by agricultural production. This tableau row portrays the *Water, AUMs, labor* row in table 5-1.
- National ag products -- Balances national consumption of agricultural products with supply transferred in from regional balances. This tableau row establishes a national price that is then translated to regional prices, taking into account typical price differences. The aggregates the *Crop balance, Livestock balance* and *Processed ag commod* rows in table 5-1.
- GHG balance -- Balances GHG accounts with their pricing. The net amount of GHG emissions arises from sequestration and emissions arising through forest production (**fc**); sequestration in wood products (**cm**); changes in sectoral sequestration when land transfers (**as**); net emissions from agricultural production (**ag**); and offsets/emissions from agricultural processing (**pg**). This row portrays the *GHG balance* row in table 5-1.

Table 5-2 Sample tableau illustrating full FASOMGHG model with regional detail but aggregate production

Equations \ Variables	Reg 1 forest production	Reg 1 Manufacture wood	Reg 1 En. Public supply	Reg 1 Non-wood inputs	Reg 1 wood product trade	Reg 1 for com to nation	Reg 2 forest production	Reg 2 Manufacture wood	Reg 2 En. Public supply	Reg 2 Non-wood inputs	Reg 2 wood product trade	Reg 2 for com to nation	Wood reg 1 to reg 2	Wood reg 2 to reg 1	Wood product demand	Reg 1 Land from Ag	Reg 1 Land to ag	Reg 2 Land from Ag	Reg 2 Land to ag	Reg 1 Produce crop/live	Reg 1 Ag processing/blend	Reg 1 water, AUMs Lab	Reg 1 trade	Reg 1 Move ag to nation	Reg 2 Produce crop/live	Reg 2 Ag processing	Reg 2 water, AUMs Lab	Reg 2 trade	Reg 2 Move ag to nation	Reg 1 to reg 2 ag transport	Reg 2 to reg 1 ag transport	Ag domestic consumption	National Ag trade	GHG payments	
Welfare			-fds	-fnw	+/-t	-fpd			-fds	-fnw	+/-t	-fpd	-fdt	-fdt	+fd	-alt	-flt	-alt	-flt	-ac	-apc	-afs	+/-s	-ad	-ac	-apc	-afs	+/-s	-ad	-adt	-adt	+ad	+/-s	+gp	
Reg 1 Timberland	+1															-1	+1																		< fl
Reg 1 Harvested Logs	-fh	+fpu	-1																																< 0
Reg 1 Wood Products		+/-p			+/-1	+1							+1	-1																					< 0
Reg 1 Non-wood input		+1		-1																															< 0
Reg 2 Timberland							+1											-1	+1																< fl
Reg 2 Harvested Logs							-fh	+fpu	-1																										< 0
Reg 2 Wood Products								+/-p			+/-1	+1	-1	+1																					< 0
Reg 2 Non-wood input								+1		-1																									< 0
National wood products						-1						-1			+1																				< 0
Reg 1 Ag land																+1	-1			+alu															< al
Reg 1 Crop balance																				+-ap	+pc		+-1	+1						+1	-1				< 0
Reg 1 Livestock bal																				+-alp	+pl			+1											< 0
Reg 1 Processed/feed																				+as	+-py			+1											< 0
Reg 1 Wat, AUMs, Lab																				+af		-1													< 0
Reg 2 Ag land																		+1	-1						+alu										< al
Reg 2 Crop balance																									-ap	+pc		+-1	+1	-1	+1				< 0
Reg 2 Livestock bal																									+-alp	+pl			+1						< 0
Reg 2 Processed/feed																									+as	+-py			+1						< 0
Reg 2 Wat, AUMs, Lab																									+af		-1								< 0
National ag products																								-1					-1			+1	+/-1		< 0
GHG balance	+fc	+cm					+fc	+cm								-as	+as	-as	+as	+ag	+pg				+ag	+pg								-1	= 0

5.3 Aggregate intertemporal portrayal

The tableau in table 5-1 portrays virtually the whole structure of the FASOMGHG programming model. However, because we fit it on a single page we only represent a single aggregate region and time period. Table 5-3 provides a companion tableau that reveals intertemporal details. However, this again requires compromises to fit on a single page. As a consequence, we portray a three period, one region model but to do this we needed to aggregate or drop much of the forestry and agricultural sector submodel detail. Note this tableau omits many features in FASOMGHG and is designed to showcase the intertemporal dimension. Also, while not portrayed here, discounting provisions are included as discussed in the integrating objective function section above.

The variables in this tableau are as follows:

- Exist stand harvest in pd -- Management of existing forest stands across harvest date alternatives. This variable is an alternative portrayal of *Exist stand* in table 5-1. Table 5-3 shows that the initial inventory (**lf**) can be managed using either different clearcut harvest dates (including never) or possibly partial cutting strategies. Upon harvest, stands yield logs at the rate **fhe**. When stands are not clearcut during the model explicit time period, they yield logs into the terminal log balance (**te**) **that** reflects long-term log yields under the assumptions of a fully regulated forest (using von Mantel's formula as discussed below). In the GHG balance, the cumulative amount of sequestration (**es**) is entered only prior to clearcut harvest but not in the clearcut period (sequestration accounting is picked up under the subsequent use of the stand). Emissions accounting is also done for all periods to reflect cumulative emissions from that period until the model end and thus persists beyond the harvest period, but is not shown here.
- Est forest land in a pd and harvest in pd -- Establishment of forests on lands that were previously forested or are from agriculture. This variable is defined over the periods in which the forest is established and harvested. This variable is an aggregate portrayal of the column *Reforest stand* and *Afforest stand* in the tableau in table 5-1. For illustrative purposes, the tableau portrays stands that can be harvested as soon as one period after planting (this is not true in the actual model). Forest establishment requires land from previous clearcuts or agriculture. That land can be used under one of a number of management alternatives involving either different clearcut harvest dates (possibly never) or partial cutting. Upon clearcut, thinning, or partial cut, stands yield harvested logs (**fhe**). When stands are not clearcut, logs are placed in the terminal log balance (**te**) **that** reflects long-term log volume under the assumptions of full regulation. In the GHG balance, the tableau portrays sequestration showing that sequestration accounting is done from the establishment period up through the period immediately prior to harvest

(expecting sequestration accounting it to be picked up under the subsequent use of the stand). Also, while not shown here, emissions accounting is also done and persists beyond the harvest period.

- Manufacture wood prods in pd -- Period specific wood products manufacturing activity. This column is a temporally enhanced depiction of *Manufacture wood prods* in table 5-1. This variable uses harvested logs in the manufacturing time period (**fpu**), while producing wood products (**p**) and, if specified, using intermediate products (also part of **p**). Finally, it enters the national GHG balance to reflect the fate of sequestered carbon in wood products from the time period of harvest through the end of the model period at the rate **cm**.
- Wood product demand in pd -- National demand for manufactured wood products. This is another portrayal of the *Wood product demand* in table 5-1 but actually represents the entire wood products marketing part of the model that is greatly aggregated here. It involves a downward sloping demand curve. This variable withdraws manufactured wood products from the balance that is time period specific. The area underneath the wood products demand curve (**fd**) appears in the objective function.
- Land from ag in pd -- Agricultural crop and pasture land moving into forestry for afforestation. This is an elaborated portrayal of *Crop land from ag* and *Pasture land from ag* in table 5-1. This variable withdraws land from the relevant agricultural land balance for the current and all subsequent time periods. It then places it in the corresponding balance for afforestation in that time period. It also reflects the hurdle costs of land transformation (**alt**). This variable enters the GHG balance, debiting the amount of agricultural soil carbon sequestered (**as**) for this and all subsequent time periods. In turn, that accounting will be picked up by the forestry establishment variables.
- Land to ag in pd -- Deforestation and movement of land into agriculture for use as crop or pasture land. This is another portrayal of *Land to ag crop land* and *Land to ag Pasture land* in table 5-1. This variable withdraws land from the forest land class bare land balance and moves it into the corresponding agricultural balance for this and all subsequent periods. It also reflects the costs of land transformation (**flt**) for stump removal and other land clearing activities. This variable enters the GHG balance, augmenting the amount of agricultural soil carbon sequestered (**as**) for this and all subsequent time periods.
- Initial tillage -- Initial allocation of agricultural lands to tillage systems at the model beginning. This variable uses land from the initial allocation (**al**) and makes it available for cropping under a particular tillage system. It enters the GHG balance **as,** beginning the agricultural soil carbon sequestration accounting in this and all subsequent periods. This is another portrayal of *Initial tillage* in table 5-1.

- Change tillage -- Alteration of tillage systems undertaken during a time period. This is elaboration on *Change tillage* in table 5-1. The variable uses land from the stock under a current tillage system and irrigation status. Such lands come from initial tillage allocation, land moving in from pasture or forestry (which moves into the conventional tilled, dryland stock), or prior tillage changes. It then makes that land available for cropping under an alternative tillage system and/or irrigation status. It enters the GHG balance (**sc**) for the current and all subsequent periods, reflecting a trajectory change in agricultural soil sequestration relative to the previously used tillage and irrigation system. This can be either positive or negative depending on whether tillage is made less or more intense.
- Produce ag in pd -- Agricultural production across crop and livestock alternatives. This portrays *Crop production* and *Livestock production* in table 5-1. Agricultural production draws from the period specific land inventory (**alu**) while producing agricultural commodities (**ay**). It affects the national GHG balance to reflect sequestration and emissions (**ag**). These entries occur not only in the time period of activity but also in all subsequent time periods to reflect the cumulative nature of the FASOMGHG accounting of emissions and offsets.
- Ag demand in pd -- Demand for agricultural commodities to reflect downward sloping demand. This is another portrayal of *Ag domestic consumption* in table 5-1 but is actually indicative of the broader modeling of agricultural commodity markets. This variable withdraws one unit of a commodity from the time period specific commodity balance and reflects the area underneath the demand curve (**ad**).
- GHG payments in pd - GHG payments in a period. This is another portrayal of *GHG payment* in table 5-1. This variable has an objective function term (**gp**) that reflects payments for the difference in the GHG account between the time period at hand and the amount within the last time period, less the corresponding change in the baseline.

The equations represented in this tableau are:

- Welfare -- Consumers' and producers' surplus across the total programming model. These terms arise across time and thus the model incorporates discounting features as discussed in the integrating objective function section above. This corresponds to the table 5-1 row *Welfare***.**
- Exist timberland -- Constrains usage of the existing forest land to that in the initial inventory (**Lf**). This equation portrays the table 5-1 row *Exist timberland.*
- Pd bare forest land -- Constrains the land used in establishing forest land use so it cannot exceed that coming from forest harvest or agriculture by time period. This is an aggregate portrayal of the table 5-1 rows *Bare forest land* and *Bare land from ag*.

- Pd harvested logs -- Limits period by period use of harvested logs to the harvested logs available. Harvested logs come from either management of private forests (**fhe**) or from unportrayed public supply. Harvested logs are used by time period specific wood products manufacturing. This portrays the *Harvested log bal* row in table 5-1.
- Pd Wood Products -- Limits period by period use of manufactured wood products to the quantity of wood products available. Wood products are produced by period specific wood products manufacturing (**p**) or can be imported (not portrayed here). Wood products are then moved into markets but can also be used as intermediate products by the regional wood product manufacturing variables (also depicted in **p**). This reportrays the *Wood products bal* row in table 5-1.
- Terminal for inventory -- Balances the perpetual even aged amount of logs from terminal standing forests (**te**) with their use (**fu**) by terminal manufacturing variables. This tableau row portrays the *Terminal for inventory* row in table 5-1.
- Terminal Wood Products -- Balances use of terminal period manufactured wood products with quantity manufactured. The structure is the same as that discussed for the *Terminal for products* row above, except for the use of terminal period logs. This tableau row portrays the *Terminal for products bal* row in table 5-1.
- Initial crop land -- Constrains the initial tillage and irrigation status assignment of agricultural land so it equals the initial land inventory available (**cl**). This represents the *Initial crop land* equation in table 5-1.
- Pd Tilled ag land -- Constrains usage of agricultural land by time period, tillagesystem, and irrigation status to the available amount of land. The supply of such land comes from either the initial assignment of the land inventory, land changing tillage systems in the current or any previous time period, or land moving in from forestry (this movement is constrained so it only can move into the conventional tillage, dryland case). Such land is used either by cropping, changes into other tillage systems, or movement of land out to forestry (again only from the conventional, dryland case). The tillage changes can reflect either intensification or deintensification. This equation represents the *Land that can change tillage* and *Tilled land* rows in table 5-1.
- Pd ag products -- Limits regional use of agricultural crop, livestock, processed products, and blended feeds to the quantity of those that are available. This tableau row portrays the *Crop balance, Livestock balance, Processed ag commod* and *Feed balance* rows in table 5-1.
- Pd GHG balance -- Balances the GHG accounts with their pricing by time period. This row portrays the *GHG balance* row in table 5-1. The coefficients as they are spread across the alternative time periods show the cumulative nature of the GHG accounting in FASOMGHG.

Several major FASOMGHG features warrant discussion as they appear in this tableau:

- The contrast between the multi-year nature of the forestry production variables and the single year nature of the agricultural variables. In particular, notice how in the third column that the forestry variable takes initial land but does not release it for reforestation until the third period. On the other hand, in the agricultural columns notice how the periods are largely separable and the land balance repeats. Also, notice how in the land transfer activities that when land is withdrawn from the agricultural balances, it is withdrawn in the time period of transfer and all subsequent periods.
- The stock accounting nature of GHG accounting. Namely, within the fifth forestry column note that the GHG balance emission and sequestration stream is multi-year in nature. These coefficients are cumulative and reflect the growing stock of sequestration. Also, on the agricultural side note that when emissions are encountered in the first time period, they also enter the balances for all subsequent periods, showing that FASOMGHG models the cumulative stock of emissions to the atmosphere
- The nature of FASOMGHG soil carbon sequestration accounting. Notice that when a forest is harvested in a particular time, the sequestration related accounting in the GHG balance is only done up until the time period immediately before harvest. In turn, the soil carbon accounting is picked up when reforestation occurs underneath the reforestation variable, or by the land transfer variable when land moves to agriculture. In forestry, the net effect of this is that forest soil carbon sequestration accounting switches from the previous stand to the next stand in the period of harvest. This is done so as to permit the model to more accurately account for the loss of carbon when land use change occurs.
- Synchronization of sequestration accounting across sectors. Soil sequestration accounting is done on both the agricultural and the forestry sides and is synchronized by the land transfer variables. Under those variables, when land transfers from agriculture to forestry, future sequestration on that land is removed from the agricultural accounts and will be picked up under the afforestation variable. Also, when land moves into agriculture, the sequestration accounting is entered from the period of movement until the model end.
- The cumulative nature of agricultural soil carbon accounting. When land is committed to a particular tillage practice, accounting is done as if it remained in that tillage practice forever. Consequently, when land changes tillage, the model reflects the differences from the state being changed from. Also, when land moves to forestry, the model debits current and future sequestration to avoid double counting.

Table 5-3 Sample tableau illustrating FASOMGHG model in a dynamic setting without regional detail with aggregate production

Equations \ Variables	Exist Stand harv in pd 1	Exist Stand harv in pd 2	Exist Stand harv in pd 3	Exist Stand harv never	Exist partial cut	Est forest Land in pd 1 harv in 2	Est forest Land in pd 1 harv in 3	Est forest Land in 1 harv never	Est forest in pd 1 partial cut	Manufacture wood prods in pd 1	Wood product demand in period 1	Est forest Land in pd 2 harv in 3	Est forest Land in 2 harv never	Est forest in pd 2 partial cut	Manufacture wood prods in pd 2	Wood product demand in period 2	Est forest Land in 3 harv never	Manufacture wood prods in pd 3	Est forest in pd 3 partial cut	Wood product demand in period 3	Terminal Manufacture wood prod	Terminal Wood product demand	Land from Ag in pd 1	Land to Ag in pd 1	Land from Ag in pd 2	Land to Ag in pd 2	Land from Ag in pd 3	Land to Ag in pd 3	Initial Tillage	Change tillage in pd 1	Produce ag in pd 1	Ag demand in pd 1	Change tillage in pd 2	Produce ag in pd 2	Ag demand in pd 2	Change tillage in pd 3	Produce ag in pd 3	Ag demand in pd 3	GHG payments in pd 1	GHG payments in pd 2	GHG payments in pd 3	
Welfare											+fd					+fd				+fd		+fd	-alt	-flt	-alt	-flt	-alt	-flt				+ad			+ad			+ad	+gp	+gp	+gp	
Exist Timberland	+1	+1	+1	+1	+1																																					≤ Lf
Pd 1 Bare forest land	-1					+1	+1	+1	+1														-1	+1																		≤ -dev
Pd 1 Harvested Logs	-fhe				-fhe					+fpu																																≤ usps
Pd 1 Wood Products										-p	+1																															≤ 0
Pd 2 Bare forest land		-1				-1						+1	+1	+1											-1	+1																≤ -dev
Pd 2 Harvested Logs		-fhe			-fhe	-fhe			-fhe						+fu																											≤ usps
Pd 2 Wood Products															-p	+1																										≤ 0
Pd 3 Bare forest land			-1				-1					-1					+1		+1								-1	+1														≤ -dev
Pd 3 Harvested Logs			-fhe		-fhe		-fhe		-fhe			-fp		-fhe				+fu																								≤ usps
Pd 3 Wood Products																		-p		+1																						≤ 0
Terminal for inventory				-te	-te			-te	-te				-te				-te		-te		+fu																					≤ 0
Terminal for prods																					-p	+1																				≤ 0
Initial tilled land																													1													< al
Pd 1 Tilled Ag land																							+1	-1					-1	+/1	+alu											≤ -adev
Pd 1 Ag products																															-ay	1										≤ 0
Pd 2 Tilled Ag land																							+1	-1	+1	-1			-1	-1			+/1	+alu								≤ -adev
Pd 2 Ag products																																		-ay	1							≤ 0
Pd 3 Tilled Ag land																							+1	-1	+1	-1	+1	-1	-1	-1			-1			+/1	+alu					≤ -adev
Pd 3 Ag products																																					-ay	1				≤ 0
Pd 1 GHG balance		es	es	es	es	fg	fg	fg	fg	cm													-as	+as					as	+/-s	ag								+1			= 0
Pd 2 GHG balance			es	es	es		fg	fg	fg	cm		fg	fg		cm								-as	+as	-as	+as			as	+/-s	ag		+/-s	ag						+1		= 0
Pd 3 GHG balance				es	es			fg	fg	cm			fg		cm		fg	cm					-as	+as	-as	+as	-as	+as	as	+/-s	ag		+/-s	ag		+/-s	ag				+1	= 0

6 CHAPTER 6 DESCRIPTION OF GREENHOUSE GAS MODELING

Since GHG coverage is one of the core features of FASOMGHG, this chapter elaborates on the fundamentals of GHG modeling therein.

6.1 GHG accounting in FASOMGHG

FASOMGHG accounts for changes in agricultural and forestry sector related net GHG emissions within a number of categories. These categories can be classified into broad categories of those involved with forest, agriculture, and biofuels feedstocks. Coverage of these categories is described above in section 3.9.1. These items are strongly interactive within model solutions. For example, land moving from agriculture to forestry will change (a) agricultural sequestration and emissions, (b) sequestration gains from afforestation, (c) emissions from forest management-related fuel usage, and (d) eventual sequestration of carbon within wood products. Thus, the implications of GHG management-induced alterations span widely across activities within the model. The nature of these alterations are discussed below.

6.2 Types of net GHG gains

Net GHG emissions can change due to altered GHG sequestration, rates of direct emissions and amounts of offsets generated. Each merits discussion.

6.2.1 Carbon sequestration

GHGs, generally in the form of carbon, can be sequestered in soils, standing trees, other vegetation, and in wood products. Sequestration refers to storage of the GHGs for more than one year. As a consequence, the sequestration definition used in the model for standing vegetation is limited to carbon storage in trees, understory and litter within both forests and plantations of woody biofuel feedstocks (poplar and willow) but excludes, for instance, carbon stored in annually cultivated crops.

Carbon sequestration is also modeled within

- Soils for lands in agricultural crop, and pasture lands
- Soils in idled lands
- Soils of land in forestry uses.
- Harvested wood products

Finally, rough sequestration accounting is included for lands that move out of forestry and agricultural production into some form of developed usage such as housing, shopping centers, roads, etc.

6.2.2 Direct GHG emissions

FASOMGHG quantifies GHG emissions produced in the forestry and agricultural sectors. As described in Chapter 3, these emissions primarily arise from fossil fuel-related processes (e.g., energy consumption), livestock production, fertilization, and rice cultivation. However they also come from other smaller sources such as residue burning. One GHG source that potentially could be modeled as an emission, but is not, is emissions from land use change (e.g., deforestation or grassland conversion to crop land uses). Instead, these sources are accounted for in the model as reduced sequestration, although these are functionally equivalent to increased emissions. In particular, FASOMGHG depicts positive credits for sequestration and when the amount of carbon sequestered is reduced by harvesting forests or changing land uses. This in effect corresponds to an emission of the sequestered carbon and is thus "penalized" as a GHG emission debit.

6.2.3 Biofuel offsets

FASOMGHG can grant credits for activities which cause an offsetting reduction in GHG emissions by sources outside the model. These credits arise via the use of agricultural commodities as biofuel feedstocks for the production of three different types of energy. The energy types are

- Electricity fueled by agricultural energy crops (switchgrass, willow and hybrid poplar), forest milling residues, or forest logs.
- Ethanol from corn or agricultural energy crops, and
- Diesel from oils derived from agricultural sources.

The basic argument for granting credits for such activities involves the concept of carbon recycling. In particular, as agricultural or forest biomass grows, it absorbs carbon dioxide from the atmosphere through photosynthesis. The carbon removed from the atmosphere in this way is sequestered in standing biomass. In turn, when the biomass is harvested and turned into energy through combustion or chemical processes, the sequestered carbon is emitted and thereby returns to the atmosphere in the form of carbon dioxide. This basically means that the net effect on atmospheric carbon of growing biomass as a fuel source that is subsequently combusted is zero. In contrast, when fossil fuels are used to generate energy, the carbon that has been stored in below-ground pools (and presumably would remain there forever were it not for its use as a fuel source) and is emitted to the atmosphere this leads to a net increase in atmospheric carbon concentration. Therefore, the substitution of biofuel feedstocks for fossil fuels can be viewed as decreasing the net carbon emissions. However, one also needs to account for the associated emissions of carbon or other GHGs that arise when the agricultural or forestry feedstocks are grown, transported and transformed into energy.

6.3 Multi Gases and climatic forcing equivalency

The multi-GHG impact of the agricultural and forestry sectors and possible manipulation of the atmospheric levels of these gases introduces multidimensional trade-offs between model variables, net GHG emissions, and the climate change implications thereof. In order to consider these trade-offs, the GHGes needed to be placed on a common footing. This is done through adoption of the 100-year global warming potential (GWP) concept and conversion of all gases to a carbon or carbon dioxide equivalent basis.

GWPs compare the abilities of different GHGs to trap heat in the atmosphere. They are based on the radiative forcing (heat-absorbing ability) of each gas relative to that of CO_2, as well as the decay rate of each gas relative to that of CO_2. The GWP allows one to convert emissions of various GHGs into a common measure, which allows for aggregating the radiative impacts of various GHGs into a single measure denominated in CO_2 or C equivalents. Extensive discuss ion of GWPs can be found in the documents of the Intergovernmental Panel on Climate Change (IPCC). In 2001, the IPCC updated its estimates of GWPs for key GHGs, but these estimates are still under debate. As a result, the FASOMGHG model uses the 1996 GWPs for the GHGs covered by the model, which are.

- CO_2 = 1
- CH_4 = 21
- N_2O = 310

When carbon dioxide equivalent results are converted to a carbon equivalent basis, a transformation is done based on the molecular weight of carbon in the carbon dioxide. This means that the carbon dioxide equivalent quantities of gas are divided by 3.667 to compute the carbon equivalent quantities.

6.4 Including GHGs in Economic Incentive Scenarios

Although FASOMGHG accounting considers all the categories of GHGs discussed above, it is possible that in specific implementation of the model that not all of the categories will be included in a GHG incentive scheme. In other words, the model tracks all GHG accounts but economic incentives may be applicable to only a subset of the accounts tracked in the model. FASOMGHG input contains parameters that authorize or de-authorize each of the individual accounts in terms of their eligibility for the GHG-related incentive payments and in terms of their use in the ultimate accounting done by the model

6.4.1 Pricing GHG Increments

FASOMGHG does not try to endogenize GHG prices. Rather it recognizes that the GHG prices will be exogenous to the agricultural and forestry sectors and takes a fixed GHG price on a carbon equivalent basis. This is a reasonable assumption given that approximately 84% of US GHG emissions arise in the energy sector, so it is clear the energy sector will play the primary role in price determination. FASOMGHG operates with an exogenously specified trajectory for carbon equivalent GHG prices by five year period. Although this input can reflect increasing GHG prices over time, users should note that the model has perfect foresight and thus rising prices can alter current economic behavior in complex ways.

Although not implemented in the current FASOMGHG version, it would be simple to introduce policy targets in terms of the total quantity of net changes in GHGs. Also, one could be introduce incentive payments for amount of GHG mitigation practices (for example acres afforested) as opposed to payments for quantities of GHGs mitigated with relatively little effort.

6.4.2 Use of a GHG Baseline

FASOMGHG does not reflect incentive payments for the total stock of GHG emissions or sequestration, but rather for deviations from an emissions, offsets and sequestration baseline. Ordinarily, FASOMGHG is initially run with a zero carbon equivalent price. In turn the resultant GHG trajectory from that run is be used as the baseline in subsequent runs. This implies that FASOMGHG does not give mitigation credit for tillage changes, adoption of practices, afforestation, and other forest management manipulations that are observed in the absence of a GHG incentive program. Any GHG changes that occur in the baseline are considered business-as-usual (or BAU) changes to which GHG effects induced by a policy can be compared to gauge the effectiveness of the policy. However, this approach may lead to analytical difficulties when technologies to promote reductions in net GHG emissions that are profitable in the absence of

GHG incentives are introduced. Namely given the profit-maximizing foundations of the model, these activities would appear in the baseline and would therefore not be considered as additional GHG mitigation beyond BAU. This can be particularly of concern when observational data suggest that some of these "profitable" practices are not typically adopted in the field. Further research is needed on the occasional disconnect between apparent and actual profitability of different management practices. The baseline is defined in the array baseline

6.4.3 Possible Inclusion of GHG Discounts

Provisions are made to allow the user to include discounts on a national basis for any of the GHG accounts. The use of a discount indicates that only a portion of the GHG quantity in a particular account may be considered a recipient of incentive payments or counted as part of the mitigation total. Reasons for discounting GHG accounts generally include

- **Permanence:** GHG emissions reduction or sequestration (more generally the latter) may be considered likely to be re-emitted in the future (beyond the time period that the model tracks), thereby indicating that the GHG benefits are only temporary.
- **Leakage**: the GHG emission reductions or sequestration tracked by the model are offset by emissions increases outside the scope of the model. Therefore net GHG reductions are lower than the account would indicate.
- **Additionality**: some of the GHG emission reductions and increased sequestration is considered part of the baseline, rather than induced by the policy.
- **Uncertainty**: the GHG quantity effects projected are based on point estimates or averages. In reality, natural and economic factors could cause variation and deviations from the expected GHG effects that the model does not explicitly capture. Recipients of GHG payments will generally discount the value of payments based on their underlying uncertainty.

Discounts related to each of these is permitted but all have a default value of zero in the table ***ghgdiscount*** in the file ***data_ghg.gms***, meaning that no downward adjustments are made for the GHG quantities considered for payment or inclusion in the policy scenario. These factors are now described in more detail.

6.4.3.1 Permanence

In terms of permanence Kim, McCarl and Murray (2005) derive a permanence discount that is based on the time when an activity accumulates offsets, the possible reversal of the activity generating a loss of carbon credits in the future, and possible maintenance costs needed to maintain the activity. They derive the permanence discount using a net present value framework that considers the relative value of nonpermanent GHG reduction with that of the perfect permanent GHG reduction. Such a discount is not necessary because, by its very nature, FASOMGHG is a multi-period net present value maximizing model that considers the exact same features that go into the derivation of the Kim, McCarl and Murray discount. As a consequence it's unlikely that the permanence discount needs to be used.

6.4.3.2 Leakage

In terms of leakage, Murray, McCarl and Lee (2004) derive a leakage discount based on the balance between GHG emission reductions stimulated with in a project area and the market induced emission gains stimulated outside of the project boundary. Murray, McCarl and Lee and Alig et al 1997 empirically demonstrate the leakage consequences of regional projects in the agricultural and forest sectors of the US both within other regions in the US and internationally. FASOMGHG, as a continental-scale US model, will consider US continental scale leakage because its GHG accounting is all inclusive or at least as close to such as we can make it. On the other hand, international leakage is not currently considered. Thus one needs to avoid double counting of domestic US leakage but may still need to include discounts that reflect international leakage. This is why the potential for adding such discounts is included in the model implementation.

6.4.3.3 Additionality

As mentioned above FASOMGHG incorporates a baseline and only pays for net GHG emission activity that occurs in addition to that in the baseline. An additionality discount as derived by McCarl reduces the creditable amount of GHG activity so that it only constitutes activity above and beyond that which would have occurred under business as usual i.e. that in the FASOMGHG baseline. As a consequence, it is unlikely that the additionality discount needs to be used.

6.4.3.4 Uncertainty

As mentioned above FASOMGHG treats net GHG emission activity as if it occurred at the average or point estimate level. An uncertainty discount as derived by McCarl and refined by Kim, McCarl and Butt (2005) reduce the creditable amount of GHG activity so that it constitutes a level of offsets expressed with a particular degree of certainty i.e. a 90% confidence interval as proposed by the Canadians in the Kyoto negotiations. Such a discount is not otherwise covered in FASOMGHG.

6.4.3.5 Avoid double-counting of discounts

Care needs to be taken if imposing these discounts on a model run, as FASOMGHG endogenously treats facets of these items. For example, FASOMGHG

- maximizes net present value, so it implicitly discounts for permanence;
- operates at the US national scale, so it directly accounts for leakage at the national level; and
- pays incentives on the difference between a baseline and the aggregate GHG trajectory for an account, so it generally considers additionality within the model structure.

Why then include discounts? Mainly, the discounting scheme is present to permit introduction of measures of exogenous items, measures of leakage outside the US, uncertainty, and the possibility of treating projects where, for example, practices are forced in and payments are adjusted for these other factors.

6.5 Which GHG categories count

International negotiations regarding GHG emission crediting have revealed that it is certainly possible that not all activity that affects net GHG emissions will be eligible for GHG payments. Consequently, FASOMGHG allows users to specify payment eligibility of each of the alternative GHG accounts. For example, under the Kyoto Protocol to the United Nations Framework Convention on Climate Change, many types of enhanced forest management, and avoided deforestation among other things are apparently not be eligible for crediting. Similarly, in recent pieces of GHG legislation considered by the US Congress, various GHG components from forestry and agriculture are either explicitly excluded or treated as entities requiring special accounting. These types of limitations in policy scope can be accommodated by altering specification of payment eligibility. This is done in the data item ***willpayforghg*** in the file ***data_ghg.gms***

6.6 GHG mitigation alternatives in FASOMGHG

Within the forest and agricultural sectors, as depicted, there are numerous management alternatives to reduce net GHG emissions below baseline levels. These are referred to throughout the document as mitigation options and are enumerated below.

6.6.1 Forest mitigation

The fundamental mechanisms within forestry that allow GHG mitigation are

- Forest management manipulations in the form of lengthened timber rotations or altered species choice.
- Expanded usage of more intensive (higher input) management. For example one can employ improved tree varieties, fertilization, thinning, partial cutting, and a number of other management alternatives.
- Expansions in forested area either through conversion of agricultural lands into forest uses (afforestation) or by avoiding conversion of forest areas into agriculture (avoided deforestation).
- Conversion of harvested wood into longer-lived wood products.
- Usage of techniques that embody less fossil fuel usage.
- Usage of harvested wood to offset fossil fuel usage by employing it as a biofuel feedstock for electrical generation or some other forms of fossil fuel substitute.

The principal GHG implications related to the above forestry manipulations involve manipulations of net sequestration and net emissions mainly altering carbon and carbon dioxide. In addition to the net mitigation pathways listed above, the net GHG emissions from forests can be altered by choice of regions and sites therein where management is altered. For example, one could choose to introduce forests on highly productive fast-growing sites to obtain higher yields and faster rates of carbon sequestration.

6.6.2 Agricultural mitigation

Agricultural mitigation can involve management manipulations that result in

- Enhancements in soil carbon sequestration,
- Reductions of GHG emissions, and
- Offsets of emissions from fossil fuels

Activities within this category can alter net emissions of the GHGs carbon/carbon dioxide, nitrous oxide, and methane. These two mitigation categories are now discussed in further detail.

6.6.2.1 Agricultural carbon sequestration enhancement

The enhancement of agricultural carbon sequestration involves management that increases the amount of carbon held in agricultural soils. The fundamental management manipulation mechanisms in this category involve alterations in:

- **Intensity of agricultural tillage**. This largely involves use of tillage alternatives that reduce the exposure of carbon in the soil to oxidation and allow larger soil aggregates to form. Such practices generally involve less soil disturbance. The practice also leaves crop residues on the soil, thereby potentially increasing carbon inputs. Tillage changes typically involve movement from more intensive tillage, such as moldboard plowing, to minimum or zero tillage practices. Additional emission reductions may also correspond with these tillage alterations because less-intensive tillage typically involves less direct fossil fuel use for tractors. However, there are also alterations in chemical usage (possibly increases in pesticide usage and alterations in rate of fertilization), which can then increase emissions from their manufacture and usage. FASOMGHG has the ability to track these indirectly induced GHG effects.
- **Relative abundance of grasslands**. This involves shifting conventional crop lands into pasture/grazing lands or retiring crop lands from active agricultural usage, for example moving them into the Conservation Reserve Program (CRP). Again, this land movement involves reductions in soil disturbance and potential increase of carbon inputs and soil storage.
- **Mix of annuals versus perennials**. Again, the basic mechanism involved here is the reduction in soil disturbance and a potential increase in carbon inputs to the soil but also includes an increase in the standing biomass**.**

6.6.2.2 Agricultural emissions reduction

Agricultural activity is responsible for a large share of total anthropogenic emissions within several GHG categories. However, agricultural CO_2 emissions related to fossil fuel usage are somewhat small, amounting to about 6-7% of the US total (EPA GHG Inventory, 2004). On the other hand, agricultural emissions of N_2O, largely from fertilization and manure, approach 50% of total US N_2O emissions, while the agricultural emission share of methane (CH_4) is also large (check % reported in Assessment Report) originating primarily from livestock herds, manure management, and rice cultivation.

There are a number of management manipulations that alter the agricultural emissions profile. Briefly, the potential manipulations inherent in the structure of FASOMGHG are

- **Lowering fossil fuel usage** -- agriculture can modify fossil fuel usage by changing tillage intensity, reducing the amount of water pumped for irrigation, reducing the usage of fossil fuels in grain drying, and otherwise manipulating the usage of fossil fuels in production. This reduces CO_2 emissions.

- **Lowering chemical usage** -- agriculture can modify the usage of chemicals that require substantial amounts of fossil fuels in their production. This includes reductions in fertilizer and pesticide use. This reduces CO_2emissions.
- **Reducing fertilization practices** -- agriculture can reduce fertilization. This reduces the N_2O emitted when nitrogen fertilizers are used as well as CH_4 and CO_2 emissions that are involved in fertilizer manufacture.
- **Reducing the size of the livestock herd** -- livestock manure is the source of CH_4 and N_2O emissions. In addition, ruminant animals (cattle) are responsible for releases of CH_4 through enteric fermentation. Thus reducing the size of the livestock herd can alter N_2O and methane emissions. Herd size reductions also alter crop and grazing demand and thus, in turn, the entire emissions/sequestration profile involved with crop and grass production.
- **Manipulating ruminant livestock feeding and rate of gain** -- cattle release CH_4 through enteric fermentation. Methane release can be altered by either: (a) improving the quality of the diet (as discussed in Johnson et al, 2003a) or (b) by using additives such as BST to increase the rate of gain.
- **Improving manure management** -- manure managed within wet handling systems leads to CH_4 release through anaerobic decomposition. Manure is also a source of nitrous oxide emissions. One may alter the way manure is managed and resultant emission profiles using different practices including digesters.
- **Rice** -- rice production generates CH_4 through anaerobic decomposition within flooded rice fields. Within FASOMGHG the only mechanism for managing such emissions involves reductions in rice acreage.
- **Legumes** -- certain nitrogen fixing legumes like soybeans and alfalfa fix nitrogen and subsequenty release N_2O. Management may be used to alter these emissions by reducing the acreage of these crops.

FASOMGHG also incoporates yet a broader set of emission reduction alternatives beyond those explicitly listed just above. These involve manipulations that have pervasive effects across the agricultural sector and include alterations in

- crop mix
- irrigated/dryland use
- regional and soil type locations of crops
- regional size and composition of the livestock herd
- composition of feed blends
- consumption patterns
- processing patterns

- import/export mixes

among many other possibilities.

6.6.3 Biofuel production

Energy sector activity is responsible for the lion's share of societal GHG emissions, with electricity production and petroleum combustion each responsible for about 40% of total US carbon/carbon dioxide emissions (better check this against the EPA inventory). Agriculture and forestry can offset energy-related emissions by providing feedstocks that can be used in energy production processes. As discussed above, such processes can greatly offset carbon emissions because the carbon present in the biofuel feedstocks which is inevitably released upon combustion would have come from the absorption of atmospheric carbon dioxide via photosynthetic processes during plant growth. As a consequence, the net emissions associated with biofuel combustion are those due to reduced emissions relative to the fossil fuels replaced by biofuel feedstock substitution.

Briefly, the potential biofuel related management possibilities that are inherent in the structure of FASOMGHG are the production of

- **Ethanol** as a replacement for gasoline through the conversion of corn, sugar cane, switchgrass, poplar and willow.
- **Electricity** through use of milling residues, harvested wood, switchgrass, poplar and/or willow as feedstocks as a substitute for coal.
- **Biodiesel** from soybeans or corn, for use in transportation fuel.

6.7 Dynamics of GHG modeling

Because FASOMGHG is a multi-period model, we needed to model the net GHG mitigation contributions of modeled activity over time. Different strategies were used to reflect these dynamic contributions depending on whether the activity of interest was sequestration, emissions reduction, or biofuel offsets. Here we chose to model the cumulative amounts of sequestration or emissions incurred during each model time period. Consequently, sequestration is modeled in terms of cumulative tons of carbon sequestered over time. For emissions and biofuel offsets, the cumulative amounts incurred in this and all previous time periods are reflected in each time period reflecting change in total climatic forcing.

6.7.1 Sequestration

For sequestration activity, the model yields non-uniform quantities over time due to the generally accepted scientific premise that carbon sequestered in an ecosystem approaches a steady state equilibrium under any management alternative. Consequently, the rate of carbon sequestration uptake diminishes after some period of time and eventually dissipates to zero (sometimes called “saturation”) when the new equilibrium is reached (West and Post). This means that FASOMGHG produces unequal and ultimately diminishing sequestration contributions over time. Namely, the amount of carbon sequestered in forests depends on the timber growth and yield curves (which exhibit diminishing growth as stands become mature) along with assumptions derived from the FORCARB modeling system (see Chapter 13) regarding carbon sequestered in soils and forest understory,). Wood products also exhibit diminishing sequestration over time as products decay and re-release carbon to the atmosphere. On the agricultural side, soil carbon sequestration gains after a change in tillage practices were ultimately assumed to diminish to zero based on the findings of West and Post (200x).

6.7.2 Emissions/Biofuel offsets

Dynamic assumptions were also made about the contribution of emissions and biofuel offset activities. The assumption used is that the emissions incurred and emissions offset by biofuels persist forever (throughout the time period covered in the model). Therefore, GHG accounts in period 2 include emissions and offsets in that period and in period 1. Therefore, emissions reduction (below baseline) are treated as “permanent” in the model

6.8 Programming model GHG implementation

The ways that the GHG features discussed above enter into the programming model are summarized in this section using a time independent summary tableau and a more precise discussion of the objective function components of the GAMS implementation. Information on how agriculture and forestry generate entries in the GHG accounts will be covered in the sector specific modeling comments later in the document in Chapters 7 - 9.

6.8.1 Tableau

A summary tableau of the GHG portion of the model appears below.

Variables =>

Equations:	Ag Production	Forest production	Seq Carbon	Emit Carbon	Emit N2O	Emit CH4	Offset Carb		
Objective function	+	+	+OCS	-OCE	-ON	-OM	+OCO		
Agric	+							<	+
Forest		+						<	+
Sequestered Carbon	+SA	+SF	-1					=	0
Emitted Carbon	+EAC	+EFC		-1				=	0
Emitted N2O	+EAN				-1			=	0
Emitted CH4	+EAM					-1		=	0
Biofuel offset carbon	+OAB	+OFB					-1	=	0

This is a simplified tableau that depicts large parts of the model. The variables in this tableau are

- **Ag Production-** Depicts numerous variables in the agricultural submodel.
- **Forest Production-** Depict numerous variables in the forestry submodel.
- **Seq Carbon** -- Cumulative net carbon sequestration by time period. The variable reflects both current activity and carryover sequestration from previous periods. This variable is contained within the ***AMOUNTGHGS*** variable in the model, which is defined for the carbon sequestration-related subset of the GHG types named above for each time period.
- **Emit Carbon** -- Cumulative net carbon emissions by time period. The variable reflects not only current activity, but also emissions from previous periods (thereby implicitly assuming that the gases remain in the atmosphere for the duration of the time frame). This variable is contained within the GAMS implementation variable ***AMOUNTGHGS*** that is defined for the carbon emission related subset of the GHG types named above for each time period.
- **Emit N2O** -- Cumulative nitrous oxide emissions by time period. This variable is contained within the GAMS implementation variable ***AMOUNTGHGS*** that is defined for the nitrous oxide-related subset of the GHG types named above for each time period.
- **Emit CH4** -- A variable that represents cumulative net methane emissions by time period. This variable is contained within the GAMS implementation variable

AMOUNTGHGS that is defined for the methane-related subset of the GHG types named above for each time period.

- **Offset Carbon** -- Cumulative net GHG biofuel offsets by time period. This variable is contained within the GAMS implementation variable ***AMOUNTGHGS*** that is defined for the biofuel related subset of the GHG types named above for each time period.

The equations in the tableau are

- **Objective function** -- Algebraic expression for net producers' plus consumers' surplus in agriculture and forestry including GHG payments for the flux in the total GHG variables minus the corresponding flux in the baseline. In terms of the GHG payment component, credits are paid for gains in the sequestration and biofuel related offsets. Debits are imposed for gains in carbon, nitrous oxide and methane emissions. These terms involve the time discounted carbon equivalent price times the carbon equivalent quantities. Each of these is adjusted as needed for discounts and eligibility for program payments.
- **Agric** -- Depicts numerous agricultural related constraints in the agriculture submodel.
- **Forest** -- Depicts numerous market and resource forestry related constraints in the forestry submodel.
- **Sequestered Carbon** -- Computes cumulative sequestration contributions during a time period for each sequestration-related GHG account and equates it with the total GHG sequestration variable (***AMOUNTGHGS***). This equation appears within the GAMS implementation equation ***GHGACCOUNTS*** that is defined for each sequestration account and time period.
- **Emitted Carbon** -- Computes the cumulative carbon emissions during each period for each carbon emission related GHG account and equates it with the GHG carbon emission variable (***AMOUNTGHGS***). This equation appears within the GAMS implementation equation ***GHGACCOUNTS*** that is defined for each carbon emission related account and time period.
- **Emitted N2O** -- Computes the change in cumulative nitrous oxide emissions from agriculture and forestry during each time period for each nitrous oxide-related GHG account with the total GHG nitrous oxide emission variable (***AMOUNTGHGS***). This equation appears within the GAMS implementation equation ***GHGACCOUNTS*** that is defined for each nitrous oxide emission related account and time period.
- **Emitted CH4** -- Computes the change in cumulative methane emissions during each time period for each methane related GHG account and equates it with the total GHG methane emission variable (***AMOUNTGHGS***). This equation appears within the GAMS implementation equation ***GHGACCOUNTS*** that is defined for each methane emission related account and time period.

- **Biofuel offset carbon Emitted CH4** -- Computes the change in cumulative biofuels offsets during each time period for each biofuel related GHG account and equates it with the total GHG biofuel offset variable (***AMOUNTGHGS***). This equation appears within the GAMS implementation equation ***GHGACCOUNTS*** that is defined for each biofuel offset related account and time period.

The terms within the tableau are:

OCS -- Net present value of payments for a change in the number of tons of carbon dioxide sequestered within each carbon sequestration account computed as the change from the last period less the change in the baseline. This equals the carbon dioxide equivalent price times an indicator of whether or not this particular sequestration category is eligible for payments adjusted for discounts and net present value concerns.

OCE -- Net present value of the costs for a change in the number of tons of carbon dioxide emitted within each carbon emission account computed as the change from the last period less the change in the baseline. This equals the carbon equivalent price times an indicator of whether or not this particular emission category incurs costs adjusted for discounts and net present value concerns.

ON --Net present value of the costs for a change in the number of tons of nitrous oxide emitted within each nitrous oxide emission-related account computed as the change from the last period less the change in the baseline. The price equals the global warming potential factor for converting nitrous oxide to carbon dioxide equivalent times the carbon dioxide equivalent price times an indicator of whether or not this particular emission category incurs costs adjusted for discounts and net present value concerns.

OCE -- Net present value of the costs incurred for a change in the number of tons of methane emitted within each methane-related account computed as the change from the last period less the change in the baseline. This equals the global warming potential for converting methane to carbon equivalent times the carbon dioxide equivalent price times an indicator of whether or not this particular emission category incurs costs adjusted for discounts and net present value concerns.

OCO -- Net present value of payments for a change in the number of tons of carbon offset by use of biofuel feedstocks within each biofuel-related account computed as the change from the last period less the change in the baseline. This equals the global warming potential for the gas at hand times the carbon dioxide equivalent price times an indicator of whether or not this particular biofuel category is eligible for payments adjusted for discounts and net present value concerns.

SA -- Net sequestration contribution by agricultural management alternatives to each sequestration category in each modeled time period. This represents activities widely across the agricultural submodel and involves current and past management possibilities involving tillage change and land use change.

SF -- Net sequestration contribution by forestry management alternatives in each time period to each sequestration category for in each model time period. This represents activities widely across the forestry submodel and involves current and past management possibilities involving harvest date alterations, forestry replanting, forest management, afforestation and deforestation.

EAC -- Net carbon emission contribution by agricultural management alternatives to each carbon emission category in each modeled time period. This represents activities widely spread across the agricultural submodel and involves current and past management possibilities involving fossil fuel use, crop mix and input manufacture.

EFC -- Net carbon emission contribution by forestry management alternatives in each time period to each carbon emission category in each model time period. This represents activities widely spread across the forestry submodel and involves current and past management possibilities involving fossil fuel use.

EAN -- Net methane emission contribution by agricultural management alternatives to each methane emission category in each modeled time period. This represents activities widely spread across the agricultural submodel and involves current and past management possibilities including fertilization, livestock herd size, and manure management.

OAM -- Net methane emission contribution by agricultural management alternatives to each methane emission category in each modeled time period. This represents activities spread widely across the agricultural submodel and involves current and past management possibilities involving livestock herd size, feeding, manure management and rice acreage.

EAB -- Net carbon offset contribution by agricultural biofuel feedstock usage management alternatives to each biofuel related emission category in each modeled time period. This represents activities widely spread across the agricultural submodel and involves current and past management possibilities involving agricultural feedstocks for ethanol, biodiesel and biofuel fired power plants.

EFB -- Net carbon offset contribution by forestry-generated biofuel feedstock usage management alternatives to each biofuel related emission category in each modeled time period. This represents activities widely spread across the forestry submodel and involves current and past management possibilities involving forest feedstock fired power plants.

6.8.2 GAMS implementation

The GHG implementation is carried into the GAMS implementation equations in two main locations: the objective function and the GHG balance equation. The main GHG variable is ***AMOUNTGHGS(periods,ghgtype)*** that is the amount of emission, sequestration or offset by GHG account (the set ***ghgtype***) and time period.

6.8.2.1 GHG part of objective function

The objective function of FASOMGHG is the equation ***WELFAR***. In that equation the following terms can be found

```
+scaldifag*
 sum(period,
    +disc(period)*wtannuity(period)
     *willpaycarbon(period)
     *carbonprice(period)
     *sum(ghgclassify(ghggas,activeghgtype),
         willpayforghg(activeghgtype)
         *gwp(ghggas)
         *([ (AMOUNTGHGS(period,activeghgtype)-AMOUNTGHGS(period-1,activeghgtype)
                                    $(date(period) > firstyear))
             -(baseline(period,activeghgtype) -baseline(period-1,activeghgtype)
                                    $(date(period) > firstyear))]
         *prod(discountsource,
 (1-ghgdiscount(activeghgtype,discountsource)))))
```

The terms excluding the GAMS operators ***sum*** and ***prod*** herein are

scaldifag -- an indicator of scaling currently set to one
period **--** current period being addressed
disc(period) **--** discount rate for current period
wtannuity(period) **--** annuity weight for annual amount over length of current period
willpaycarbon(period) **--** indicates whether GHG payment program in place this period
carbonprice(period) **--** carbon equivalent price per ton in this period
ghgclassify(ghggas,activeghgtype) - indicates the GHG gas involved with this account
ghggas—type of GHG -- carbon, carbon dioxide, nitrous oxide or methane
activeghgtype -- GHG account as listed above
willpayforghg(activeghgtype) -- payment or cost eligibility for this account (0, +1 or -1)
gwp(ghggas) -- global warming potential
AMOUNTGHGS(period,activeghgtype) -- endogenous variable giving amount of GHG account by period where period-1 references the amount in the previous period
baseline(period,activeghgtype) **--** baseline amount of this GHG account by period where period-1 references the amount in the previous period
discountsource **--** types of discounts applied -- additivity, permanence, additionality and uncertainty
(1-ghgdiscount(activeghgtype,discountsource)) **--** quantity fully paid for relative to a discount

The net result of all this is the amount of GHG (***AMOUNTGHGS***) as it deviates from amount in the previous period less the change in the baseline (***baseline***) is computed. Then that amount is adjusted downward for market discounts (**1-ghgdiscount**). In turn the result is converted to carbon dioxide equivalent by multiplying by ***gwp.*** Then the result is multiplied by the carbon equivalent price (***carbonprice***). Subsequently, we adjust for whether this account is eligible and whether it is a sequestration credit, offset credit or emission cost (***willpaycarbon***). Finally we multiply by a facto that adjusts from an annual to an annuity basis (***wtannuity*)** then discount back to present value (***disc***). This is summed over all time periods and GHG accounts to form the total net emission change objective function contribution. The term is also scaled so it matches the other parts of the objective function (***scaldifag***)

6.8.2.2 GHG equations

In the model the GHG amounts by account are summed up in the equation ***GHGACCOUNTS(currentperiod,activeghgtype).*** This involves many forest, agricultural and intersectoral land movement terms. Discussion of them is provided in Chapters 7-9.

7 CHAPTER 7 FOREST SECTOR SUBMODEL

Here we detail the way the forest sector submodel covers important forest sector characteristics. To do this we first overview the forest sector submodel. Then we illustrate model subcomponents that address key forest sector characteristics. Later we present an algebraic representation of the whole forestry submodel.

7.1 Whole forest model overview

A broad overview of the forestry submodel appears in the tableau within table 7-1. This tableau shows the key forest sector features involved with

- Forest harvest
- Forest stand establishment
- Wood products manufacturing
- Wood products demand
- Domestic wood product transport
- International trade in wood products
- Forest land resources
- Forest non-wood inputs

The tableau also shows interaction with other sectors including land moving in and out from agriculture and land movement to development. Finally, it illustrates GHG involvement.

Table 7-1 Sample tableau illustrating forest sector submodel aspects

Equations \ Variables	Clearcut exist stand	Partial cut exist stand	Reforest land	Afforest land	Timber production cost	Manu. US wood prod	Terminal manufacture	Manufacture Canada wood prod	Canadian harvest	Canadian transport	Domestic transport	Public supply	Non-wood inputs	Land from ag	Land to ag	US Wood product demand	Wood products import	Canadian product demand	Terminal product demand	GHG payments	
Welfare					-1				-k	-a	-b	-c	-d	-e	-f	g	-n	h	I	j	
Exist timberland	1	1																			= l
Harvested clearcut forest land	-1		+/-1	-1											1						= -dev
Land from ag				1										-1							= 0
US harvested logs	-he	-hp	-hr	-ha		y															= usps
Canada harvested logs								Y	-1												= 0
Production cost	ce	cp	Cr	ce	-1																= 0
US manufactured wood prods						-1				-1	+/-	-1				1	-1				= -exp
Canada manufactured wood prods								-1		1								1			= Candem - OSxpts
Milling residues						+/-	+/-	+/-													= 0
Non-wood input						1	1	1					-1								= 0
Terminal inventory	-te	-tp	-tr	-ta			Y														= 0
Terminal manufactured wood products							-1												1		= 0
GHG balance	ce	cp	cr	ca		cm														-1	= 0

The equations (rows) in the tableau are:

- *Welfare* -- The sum of consumers' and producers' surplus net of transport and other costs. This is the forestry component of the objective function that is maximized to find the market equilibrium solution. The terms incorporated fall into several classes. Areas underneath demand curves appear in association with the variables labeled *Wood product demand, Wood product export* and *Terminal product demand.* These depict positive contributions to the objective function. The objective function term associated with the variable *GHG payments* give the GHG payments and are also a positive contribution to the objective function. Simultaneously the objective function contains terms that subtract the area underneath the supply curves for *Non-wood input* items, and *Wood product import*. The terms associated with the variables *Production cost, Canadian transport, Domestic transport, Land from ag,* and *Land to ag* give the costs of purchasing items involved in the total production, processing land transformation, and commodity movement that are assumed to be available at a fixed price. The GAMS implementation equation ***WELFAR*** is represented by this tableau row.
- *Exist timberland* -- Limits use of the initial forest inventory in acres to the amount of inventory available. All existing stands at the start of the problem are allocated to some management regime (including no management or reserved). This equation is defined by age of stand (the GAMS set ***cohort***), FASOMGHG log producing region (***logregions***), land suitability class (***class***), type of forest owner (***pvtlogowner***), type of forest stand (***type***), site index (***site***) and type of management to which the stand has been subjected (***MgtIntensity***). The GAMS implementation equation ***FORINVENTORYA*** is represented by this tableau row.
- *Harvested clearcut forest land* -- Balances land obtained from clearcut timber harvest with its subsequent use for reforestation or land use change. The land use change possibilities are movements to agriculture or movement to developed use. Afforestation is a potential source of land but only after the first rotation. The variable constitutes both a supply and a use (+/-) of land. Bare land is consumed by forest establishment and upon harvest is released for subsequent reuse. This equation is defined by log producing region (***logregions***), land suitability class (***class***), forest owner (***pvtlogowner***), type of succeeding forest stand (***sucessorgroup***), site index (***site***) and time period (***period***). The GAMS implementation equation ***FORLANDBALANCE*** is represented by this tableau row.
- *Land from ag* -- Balances land coming into forestry from agriculture with afforestation for the first forest rotation. All subsequent rotations afforested lands are handled within the *Harvested clearcut forest land* balance as reforestation. This equation is defined by log producing region (***logregions***), land suitability class (***class***), forest owner

(***pvtlogowner***), site index (***site***) and time period (***period***). The GAMS implementation equation ***FORAFFORLANDBALANCE*** is represented by this tableau row.

- *US harvested logs* -- Balances logs harvested with their use in wood products manufacturing. Harvested logs arise from existing stands, reforested stands, and afforested stands under clearcut management and thinning or partial cut harvest regimes. Logs cut from public lands also enter as an exogenous supply source (**usps**). This equation is defined by time period (***period***), log producing region (***logregions***), forest owner (***pvtlogowner***), and log type (***logproducts***). Cases within the GAMS implementation equations ***FORBALEXHRV, FORBALEXHPC, FORBALNEWHRV***, ***FORBALNEWHPC,*** and ***FORWDBALANCE*** are represented by this tableau row.
- *Canada logs* -- Balances logs obtained from Canadian harvest (that varies with log price) with Canadian wood product manufacture. This equation is defined by time period (***period***), Canadian region (***reg***), forest owner (***pvtlogowner***), and product type (***logproducts***). Cases within the GAMS implementation equations ***FORWDBALANCE*** are represented by this tableau row.
- *Timber production cost* -- Computes total forest production cost across a number of categories such as establishment and fertilization and equates it with the forest production cost variable. This equation is defined by time period (***period***), and log producing region (***logregions***). The GAMS implementation equations ***FORCOSTBAL*** are represented by this tableau row.
- *US manufactured wood products* -- Balances wood product production with consumption. Wood products come from from wood product manufacturing plus imports from Canada and off-shore. Consumption comes from domestic demand, exports and intermediate product use. This equation is defined by time period (***period***), wood manufacturing region (***activewoodregions***), and product type (***woodproducts***). Cases within the GAMS implementation equations ***FORWDBALANCE*** are represented by this tableau row.
- *Canada manufactured wood prods* -- Balances the product yield from Canadian manufacturing with Canadian consumption and exports to the US. This equation is defined by time period (***period***), Canadian region (***activewoodregions***), and product type (***woodproducts***). Cases within the GAMS implementation equations ***FORWDBALANCE*** are represented by this tableau row.
- *Milling residues* -- Balances the supply of milling residues with their use in further manufacturing and is designated separately for US and Canadian conditions. This equation is defined by wood manufacturing region (***activewoodregions***), residue type (***residues***) and time period (***period***). Cases within the GAMS implementation equations ***FORWDRESBAL*** are represented by this tableau row.

- *Non-wood input* -- Associates non-wood inputs with manufacturing activity. Non-wood inputs encompass costs of log harvest and hauling to mills along with the costs of non-wood inputs used in manufacturing. The cost of supply of non-wood inputs vary with the volume. This equation is defined by type of non-wood input being supplied (***woodsupplytype***), wood manufacturing region (***activewoodregions***), product being manufactured (***woodproducts***) and time period (***period***). Cases within the GAMS implementation equations ***FORWDNWCEQ*** are represented by this tableau row.
- *Terminal inventory* -- Computes the log volume that would be obtained under a perpetual even-aged management system from unharvested timber stands in inventory at the end of the explicit model time frame and balances that with terminal period wood products manufacturing. This equation is defined for the terminal (period "9999") period by log producing region (***logregions***), forest owner (***pvtlogowner***), and product type (***logproducts***). Cases within the GAMS implementation equations ***FORBALEXHRV, FORBALNEWHRV***, and ***FORWDBALANCE*** are represented by this tableau row.
- *Terminal wood products* -- Balances the wood products obtained from processing with consumption for the perpetual terminal period. This equation is defined for the "9999" time period, by wood manufacturing region (***activewoodregions***), and product type (***woodproducts***). Cases within the GAMS implementation equations ***FORWDBALANCE*** are represented by this tableau row.
- *GHG balance* -- Computes forest-related GHG emissions and sequestration from forest soils, litter, and understory; growing trees; and wood products. This includes the fossil fuel related emissions from forest production. Net payments to fluxes in GHGs are computed in the objective function. This equation is defined by time period (***period***), and GHG account (***ghgtype***). Cases within the GAMS implementation equations ***GHGACCOUNTS*** are represented by this tableau row.

The variables (columns) in the tableau are

- *Clearcut exist stand* -- Clearcuts/even-aged management of existing stands. Alternatives alliow variance in harvest age, thinning and management intensity. The variable requires land in the initial inventory and production cost inputs while generating harvested logs and affecting the GHG balance. Upon harvest, land is released for subsequent reforestation or land use change. This variable is defined by harvest period (***period***), stand age (***cohort***), log producing region (***logregions***), land suitability class (***class***), forest owner (***pvtlogowner***), forest type (***type***), site index (***site***), management applied (***mgtintensity***), and possible subsidy-related policy (***policy***). Cases within the GAMS implementation variable ***FORPRDEXIST*** are represented by this tableau column.
- *Partial cut exist stand* -- Partial cutting of existing stands. The variable uses land from the inventory and production cost inputs while generating harvested logs and affecting the

GHG balance. Land allocated to partial cutting can be maintained in partial cutting or clearcut harvested and shifted to even-aged management in subsequent periods. Land allocated to partial cutting is not released for subsequent reforestation or land use change after a partial cut. This variable is defined by eventual harvest period (***period*** -- which can be never), stand age (***cohort***), log producing region (***logregions***), land suitability class (***class***), forest owner (***pvtlogowner***), forest type (***type***), site index (***site***), partial cut related management practice applied (***mgtintensity***), and possible subsidy-related policy (***policy***). Cases within the GAMS implementation variable ***FORPRDEXIST*** are represented by this tableau column.

- *Reforest Land* -- Establishment of forests on previously forested land. While not fully represented here such stands have a choice of an array of management intensities nd harvest methods. Bare land that was previously in forest is required as are forest production cost inputs. Harvested logs are generated and an entry placed in the GHG balance. This land, when clearcut, is released for subsequent reforestation or land use change. This variable is defined by stand establishment period (***period***), eventual harvest period (***period*** -- which can be never), log producing region (***logregions***), land suitability class (***class***), forest owner (***pvtlogowner***), forest type (***type***), site index (***site***), management practice applied (***mgtintensity***), and possible subsidy-related policy (***policy***). Cases within the GAMS implementation variable ***FORPRDNEW*** are represented by this tableau column.
- *Afforest Land* -- Establishment of forests on land transferring from agricultural crops or pasture. Land is classed as afforestation for the first forest rotation only. Although not fully represented here such stands have a choice of harvest age, choice of cutting regime including whether or not they're managed through thinning, partial cut or clearcut systems and choices of management intensity. After the first forest rotation this land is then treated within the reforest land variable. The variable requires land from agriculture and production cost inputs while generating harvested logs and affecting the GHG balance. This land, if clearcut, is released for subsequent reforestation or land use change. This variable is defined by stand establishment period (***oldperiod***), eventual harvest period (***period*** -- which can be never), log producing region (***logregions***), land suitability class (***class***), forest owner (***pvtlogowner***), stand type (***type***), site index (***site***), management practice applied (***mgtintensity***), and possible subsidy-related policy (***policy***). Cases within the GAMS implementation variable ***FORPRDNEWAFFOREST*** are represented by this tableau column.
- *Production cost* -- Costs forest production (silvicultural) activities in the objective function. This variable is defined by log producing region (***logregions***) and time period (***period***). Cases within the GAMS implementation variable ***FORPRDCOST*** are represented by this tableau column.

- *Manufacture US wood products* -- Wood products manufacturing. Several functions are encompassed by this variable, including transformation of logs into intermediate products, transformations of intermediate products into final wood products; and downgrading of logs into lower use classes. The variable requires logs, milling residues and/or immediate products along with non-wood production costs. They generate intermediate products, milling residues and final products. They enter the fate of the sequestered carbon in harvested wood products into the GHG balance. This variable is defined by time period (***period***), wood producing region (***activewoodregions***), product being manufactured (***woodproduct***), process being used (***process***), and input mix (***inputmix***). Cases within the GAMS implementation variable ***FORWDMANUFACT*** are represented by this tableau column.
- *Terminal wood products manufacture* -- Wood manufacturing in the terminal period. This is essentially identical to the just discussed Manufacture US wood products variable but deals with the logs and products available in the terminal period. This variable is defined for the terminal time period (***"9999"***), wood producing region (***activewoodregions***), product being manufactured (***woodproduct***), process being used (***process***), and input mix (***inputmix***). Cases within the GAMS implementation variable ***FORWDMANUFACT*** are represented by this tableau column.
- *Manufacture Canada wood* -- Canadian wood manufacturing. This essentially identical to the Manufacture US wood products variable but deals with logs and products generated in Canada. This variable is defined by time period (***period***), Canadian wood producing region (***activewoodregions***), product being manufactured (***woodproduct***), process being used (***process***), and input mix (***inputmix***). Cases within the GAMS implementation variable ***FORWDMANUFACT*** are represented by this tableau column.
- *Canadian transport* -- Movement of Canadian-produced wood products into US markets. Goods are used from the Canadian wood products balance and supplied into US regional balances while incurring transport cost in the objective function. This variable is defined by Canadian region of origin (***activewoodregions***), region of destination (***activewoodregions2***), wood product involved (***woodproducts***) and time period (***period***). Cases within the GAMS implementation variable ***FORWDTRANSPORT*** are represented by this tableau column.
- *Domestic transport* -- Interregional transport of US-produced wood products. Goods are used from the wood products balance equation for the region of origin and are supplied into the region of destination while incurring transport cost in the objective function. This variable is defined by region of origin (***activewoodregions***), region of destination (***activewoodregions2***), wood product involved (***woodproducts***) and time period (***period***). Cases within the GAMS implementation variable ***FORWDTRANSPORT*** are represented by this tableau column.

- *Public supply* -- Logs harvested from public lands. Harvested logs are supplied and incur a cost equal to the log price. This variable is defined by region (***activewoodregions***), log type (***logproducts***) and time period (***period***). Cases within the GAMS implementation variables ***FORWDLOGSUPPLY*** are represented by this tableau column.
- *Non-wood inputs* -- Supply of non-wood inputs to log harvest and hauling and wood products manufacture according to an upward sloping supply cost schedule. The variable supplies one unit into the non-wood input equation and has the area underneath the non-wood supply equation in the objective function. This variable is defined by type of supply (***woodsupplytype***), manufacturing region (***activewoodregions***), wood product being made (***woodproducts***), time period (***period***) and step (***steps***). Cases within the GAMS implementation variables ***FORWDNWCS*** are represented by this tableau column.
- *Land from ag* -- Land use change from agriculture to forestry. Land is drawn on the agricultural side from either the pasture or crop land equations and is placed into the forestry equation at a hurdle cost. This land can only be used by the *Afforest Land* variable. This variable is defined by log producing region (***logregions***), land class (***class***), and time period (***period***). Cases within the GAMS implementation variables ***LANDFROMAG*** and ***CONVRTFROMAG*** are represented by this tableau column.
- *Land to ag* -- Land use change from forestry into agriculture. Land is withdrawn on the forestry side from the land available for reforestation and placed into the agricultural crop or pasture land balances incurring a land transformation cost. This variable is defined by log producing region (***logregions***), land class (***class***), cost step (***three***), and time period (***period***). Cases within the GAMS implementation variables ***LANDTOAG*** and ***CONVRTTOAG*** are represented by this tableau column.
- *Wood Product demand* -- Domestic demand for wood products in US markets. The variable withdraws from the wood products balance and contains an objective function term that equals the area underneath the demand curve. This variable is defined by region (***activewoodregions***), wood product involved (***woodproducts***), and time period (***period***). Cases within the GAMS implementation variables ***FORWDDEMAND*** are represented by this tableau column.
- *Wood product export* -- Export demand for wood products from US markets. The variable withdraws one unit from the wood products balance equation and contains an objective function term that equals the area underneath the product specific export demand curve. This variable is defined by region (***activewoodregions***), wood product involved (***woodproducts***), and time period (***period***). Cases within the GAMS implementation variables ***FORWDDEMAND*** are represented by this tableau column.
- *Wood Products import* -- Import supply of wood products into US markets. The variable adds into the wood products balance equation and contains an objective function term that equals the negative of the area underneath the product specific supply curve. This

variable is defined by region (***activewoodregions***), wood product involved (***woodproducts***), and time period (***period***). Cases within the GAMS implementation variables ***FORWDSUPPLY*** are represented by this tableau column.

- *Terminal product demand* -- Demand for wood products in the terminal period. This variable is essentially identical to all of the domestic and export demand variables above but deals with products produced in the terminal period. This variable is defined by type of demand (***wooddemandtype***), region (***activewoodregions***), and wood product involved (***woodproducts***). Cases within the GAMS implementation variables ***FORWDDEMAND*** are represented by this tableau column.
- *GHG payments* -- Payments or taxes for changes in net GHG emissions above those in the baseline by inventory account. This variable is defined by time period (***period***), and GHG account (***ghgtype***). Cases within the GAMS implementation variables ***GHGACCOUNTS*** are represented by this tableau column.

The parameters in the tableau are:

a -- the per unit transport costs of moving wood products from Canada into the US
b -- the per unit transport costs of moving US wood products between regions
c -- the per uit price of public timper supply
d -- the area underneath the supply curve for US non-wood inputs which includes non-wood items used in wood products manufacture along with hauling and harvest for log movements from the woods to manufacturing facilities
e -- the hurdle costs of moving land from agriculture
f -- the land transformation costs involved in moving previously forested land into agriculture
g -- the area underneath the demand curves for US wood products
m -- the area underneath the export demand curves for exports of US wood products
n -- the area underneath the supply curves for imports into the US of wood products
h -- the area underneath the Canadian demand curves for wood products
i -- the area underneath wood products demand curves in the terminal period
j -- the per unit payments/taxes that apply to changes above those in the baseline for net GHG emissions
l -- the amount of land in the initial forest inventory by type of stand
dev -- the amount of land moving out of the forest inventory into developed uses
exp -- the amount of exported wood products (exogenous)
he -- the volume of logs obtained per acre of harvested existing forest
hp -- the volume of logs obtained per acre of partially cut existing forest
hr -- the volume of logs obtained per acre of clearcut or partially cut reforested forest
ha -- the volume of logs obtained per acre of clearcut or partially cut afforested forest during the first rotation
y -- the amount of logs used in the manufacture of one unit of intermediate or final manufactured wood product
usps -- the exogenously specified amount of logs obtained from US publically owned forests

candem – Canadian demand
OSexprts – Canadian off shore exports
ce -- the net carbon emission profile in a number of accounts from existing forests including the sequestration increment and the fossil fuel consumption related emissions
cp -- the net carbon emission profile in a number of accounts from partially cut forests including the sequestration increment and the fossil fuel consumption related emissions
cr -- the net carbon emission profile in a number of accounts from reforested forests including the sequestration increment and the fossil fuel consumption related emissions
ca -- the net carbon emission profile in a number of accounts from afforested forests including the sequestration increment and the fossil fuel consumption related emissions
cm -- the fate of carbon sequestered in wood products
+/- -- indicates that the coefficient in this location can either be positive or negative in sign
te -- terminal period log yield from management of any unharvested existing forests according to a perpetual even-aged management scheme
tp -- terminal period log yield from management of any unharvested existing partially cut forests according to a perpetual even-aged management scheme
tr -- terminal period log yield from management of any unharvested reforested forests according to a perpetual even-aged management scheme
ta -- terminal period log yield from management of any unharvested afforested forests according to a perpetual even-aged management scheme

7.2 Model elements

In this section we further highlight key forest sector characteristics and the ways that the FASOMGHG model structure accommodates them.

7.2.1 Stand representation

Forest stands[3] grow at differential rates due to differences in management, site quality, ownership, climate, tree age and tree species. The FASOMGHG forest stand and inventory representation reflects these characteristics on current timberland and potentially afforested land in the contiguous 48 states (Alig et al. 1998) under private ownership. Pubic lands are treated exogenously. Private timberland is characterized by:

- Geographic region (nine as in figure 3.xx),

[3] We deal with aggregates representing strata that cover relatively large areas; for example, by region, ownership, forest type, etc.. For simplicity, we will term them modeled "stands" as is common in forestry discussions.

- Type of land owner (private lands only- two owners)
- Land use suitability for transfer to or from agriculture (5 groups),
- Forest types (ten) as defined below,
- Site productivity potential for wood volume growth (three levels) as defined below,
- Management intensity (23 timber management regimes applied to the area) as defined below, and
- Five year age cohorts up to 100+ years of age.

7.2.1.1 Regions

Forest production occurs in 9 of the 11 regions used in FASOMGHG to depict the lower 48 states (table 3-1). While timber production is represented in all 9 of these regions, the major producing regions are (a) the Pacific Northwest west of the Cascade Mountain Range (PNWW); (b) the South Central (SC) and (c) the South East (SE). National Forest timber and Canadian production are also represented but with exogenous harvest levels.

7.2.1.2 Land owner

The only forested stands explicitly represented are those owned by private parties. Two ownership classes are defined

- Forest industry (FI) --private lands owned by companies or individuals operating wood manufacturing plants.
- Non industrial private forest --private lands owned by individuals or companies who do not operate wood manufacturing plants.

7.2.1.3 Land use suitability

Five land suitability classes are used in tracking timberland:

FORONLY -- Timberland acres that are not suitable for conversion to agricultural uses;
FORCROP -- Acres that begin in timberland but could be converted to crop land uses
FORPAST -- Acres that begin in timberland but could be converted to pasture uses
CROPFOR -- Acres that begin in crop land uses but are converted to timberland. All afforested crop land is in this category and after conversion into forest can be returned to agricultural crop land later in the model time frame.
PASTFOR -- Acres that begin in pasture land uses but are converted to timberland. All afforested pasture land is in this category and after conversion into forest can be returned to agricultural pasture later in the model time frame.

The classification name identifies the type of allowed land use changes. The second part identifies the type of use for which the land is potentially suited for conversion (crop, pasture, or forest only) and by the prior use (first part of name). For example, FORCROP is land that was in forest cover and is suitable for conversion to crop land.

7.2.1.4 Forest type

Ten forest types are defined. These are listed in Table 7-2. The definitions used in all regions but the SC, SE, and PNWW are limited to HARD and SOFT. In the SC and SE regions the definitions BOT_HARD, UP_HARD, NAT_PINE, OAK_PINE, and PLNT_PINE are used. The three definitions DOUG_FIR, OTH_SWDS, and HARDWOODS are used in the PNWW region.

Table 7-2 Forest types used in the model

Forest Type	Description
SOFT	Broad softwood forest type
HARD	Broad hardwood forest type
BOT_HARD	Bottomland hardwood forest type
UP_HARD	Upland hardwood forest type
NAT_PINE	Natural pine forest type
OAK_PINE	Oak-pine forest type
PLNT_PINE	Planted pine forest type
DOUG_FIR	Douglas-fir forest type
OTH_SWDS	Representative softwood forest type, excluding Doug-fir
HARDWOODS	Composite hardwood forest type for the PNWW region

7.2.1.5 Site productivity

Three site productivity types are defined. These are based on a classification of forestland in terms of potential annual cubic-foot volume growth per acre at culmination of mean annual increment in fully-stocked natural stands (Smith et al. 2001). Specific productivity ranges can vary by region and an example for the South is given in Table 7-3 below.

Table 7-3 Timberland site classes for the South

Site Class	Cubic feet per acre per year
LO	20-49 cubic feet
MED	50-84 cubic feet
HI	85+ cubic feet

7.2.1.6 Management intensity classes

We allow several different levels of timber management intensity for newly regenerated timber stands. These management intensity classes (MICs) were largely derived from the MICs developed for modeling by the Aggregate TimberLand Analysis System (ATLAS) (Mills and Kincaid, 1992) in the 2000 RPA Timber Assessment (Haynes, 2003, Mills and Zhou, 2003). The number and type of MICs vary by region, forest type, and site class. The largest numbers are in the SC, SE and PNWW where the bulk of the nation's timber harvest originates. In other regions, two relatively low intensity levels of timber management are used that approximate the regional forms of timber management: passive (PASSIVE) -- depicting no management intervention of any type between timber harvests of naturally-regenerated aggregates; and low (LO) -- custodial timber management of naturally-regenerated aggregates (Adams et al. 1996).

The management options in the South and PNWW regions involve a combination of harvest method -- (clearcut or partial cutting) and silvacultural practices including thinning. The management alternatives are listed in table 7-4.

Table 7-4 Forest management intensity codes (MICs) used

MIC Code	Description
AFFOR	Afforestation of bottomland hardwood (SE and SC)
AFFOR_CB	Afforestation of hardwood and softwood forest types (CB)
LO	Natural regeneration (or afforestation) with low management
NAT_REGEN	Natural regeneration with low management (PNWW)
NAT_REGEN_PART_CUT_HI	Partial cutting with high level of management (PNWW)
NAT_REGEN_PART_CUT_LO	Partial cutting with medium level of management (PNWW)
NAT_REGEN_PART_CUT_MED	Partial cutting with low level of management (PNWW)
NAT_REGEN_THIN	Natural regeneration with a commercial thin (PNWW)
PART_CUT_HI	Partial cutting with medium level of management (SE and SC)
PART_CUT_HI+	Partial cutting with high level of management (SE and SC)
PART_CUT_LO	Partial cutting with low level of management (SE and SC)
PASSIVE	Passive management (minimal amount of management)
PLANT	Plant with no intermediate treatments (PNWW)
PLANT_THIN	Plant with medium level of management (PNWW)
PLANT+	Plant with high level of management (PNWW)
PLNT_HI	Planted pine with high level of management (SE and SC)
PLNT_HI_THIN	Planted pine with commercial thin and high level of management (SE and SC)
PLNT_LO_THIN	Planted pine with commercial thin and no intermediate treatments (SE and SC)
PLNT_MED	Planted pine with medium level of management (SE and SC)

PLNT_MED_THIN	Planted pine with commercial thin and medium level of management (SE and SC)
RESERVED	Reserved from harvest
SHORT_ROTSWDS	Short rotation softwoods with high level of management (SE and SC)
TRAD_PLNT_PINE	Planted pine with no intermediate treatments (SE and SC)

Additional details and supporting data relative to these alternatives are described in Section xx.2.

7.2.1.7 Cohorts

For an even-aged stand, a FASOMGHG stand is characterized by a range of ages for the trees therein. Even-aged stands are those where 70% or more of the tree stocking falls within a 30-year grouping. We use five-year cohorts to classify even-aged stands, to provide indications about how long different stands have occupied the land. In the South the first year of occupancy is commonly trees that are older as trees are transplanted in at older ages. The cohorts for land occupancy are 0-4, 5-9, 10-14, 14-19 and so on in five year intervals up to 95-99 and 100+. We do not differentiate between age groups beyond 100 years.

7.2.2 Initial inventory

The initial forest inventory was developed using inventory data from the Forest Service's 2000 RPA Timber Assessment (Haynes, 2003). Each stratum is represented by the number of timberland acres it contains. Inventories on public lands are not explicitly modeled and public timber harvests in the US are taken as exogenous. We do not model or project the Canadian timber inventory on public (provincial) or private lands.

The basic constraint in the model reflecting the initial inventory requires that all of the inventory acreage of stands in existence at the start of the model projection be allocated to the management variables for existing stands across harvest possibilities. In the GAMS implementation this is the ***FORINVENTORYA*** equation which is defined for each stand as ***FORINVENTORYA(cohort,allreg,class,pvtlogowner,type,site,MgtIntensity)*** where the sets are

cohort -- tree age cohort
allreg -- log producing region
class -- land suitability for agriculture or forestry
pvtlogowner -- type of private owner
type -- forest type
site -- site productivity class
mgtintensity -- management intensity class

These areas are allocated to either timber harvest in some current or future period or a never harvest possibility using the ***FORPRDEXIST*** variable, which is defined in GAMS with set dependency as follows:

FORPRDEXIST(allperiods,cohort,allreg,class,pvtlogowner,type,site,MgtIntensity,policy).

The sets contained herein beyond those defined just above are

allperiods -- the period in which the stand is clearcut harvested (2000,2005,2010,…) one possibility for which is never (9999)
policy -- the policy under which these acres are managed, which is generally the BASE, but could be another definition when subsidy or other policy programs are being simulated.

The basics of the GAMS implementation of this equation is

+ sum((period,policy),
FORPRDEXIST(period,cohort,reg,class,pvtlogowner,type,site,MgtIntensity,policy)))
= invent(cohort,reg,class,pvtlogowner,type,site,MgtIntensity)

This requires that the area cut from pre-existing timberlands across the different harvest periods under the available policies equal the existing (or initial period) acres in the inventory. Empirically, the inventory data in the GAMS parameter ***invent*** give the acreage in 1000 acres**.** Thus, the units of ***FORPRDEXIST*** are also in 1000 acres.

Note that existing stands allocated to a partial cutting regimes can be clearcut (if it is optimal to do so) and replanted to some new even-aged or partial cutting regime, or they may remain in partial cutting for the entire projection (with the clearcut harvest period being "never"). This permits stands to move back and forth between even and partial cutting regimes.

7.2.3 The new and existing stands distinction plus isnew/isnewexist

A very important distinction in the model is the difference between new and existing stands and the accompanying use of the sets ***isnew*** and ***isexist***.

7.2.3.1 New versus existing stands

Timberland areas are differentiated into "existing" and "new" activities, depending on whether the timber stand was present in the initial inventory or was created during the course of the projection. By definition a new stand does not exist at the beginning of a model run but rather will come into the inventory only upon the reforestation of a harvested existing stand or upon the afforestation of land moving over from agriculture. Yields for existing stands are in ***existyld*** for clearcuts and ***existyldpc*** for thinning and partial cuts. The associated variable is ***FORPRDEXIST(period,cohort,allreg,class,pvtlogowner,type,site,mgtintensity,policy).*** Note that the only time dependent set used in the definition of this variable is the time of harvest which is identified by the set ***period*** in the definition above but also includes 9999 for the never clearcut possibility**.** Yields for existing stands are in ***newyld*** for clearcuts and ***newyldpc*** for thinning and partial cuts. The associated variable is ***FORPRDNEW(period,when,allreg,class,pvtlogowner,type,site,mgtintensity,policy)*** for reforested stands and ***FORPRDNEWAFFOREST(periods,when,allreg,class,pvtlogowner,type,site,MgtIntensity,policy)*** for the first rotation of an afforested stand. Two time dependent sets are used in the definition of these variables. One is the time of stand establishment which is identified by the set ***period*** in the definition above**.** The other is the time of harvest of the stand which is identified by the set ***when*** giving how long after planting that harvest occurs**.**

7.2.3.2 Isnew and isexist

Two multidimensional sets are associated with the new and existing stand definitions that are used to indicate when stands may potentially exist in the inventory. These are ***isnew*** and ***isexist*** and have all the same dimensions as the variables above except for the harvest dimension. These sets have active (non-zero) elements only when a stand truly either exists (having inventory, yield and cost) or has the capability to exist through afforestation or reforestation of a harvested existing stand along with accompanying yield and cost data. These multidimensional sets are calculated based on the model data in the GAMS file ***model_update.gms***. They are repeatedly used in calculations to limit the number of variables or constraints that the model generates. For example, we need not create a variable for the 60-year old age class in the initial inventory if there are no 60-year old acres in the starting inventory. Furthermore the ***FORINVENTORYA*** constraint requires that all acres in the initial inventory be allocated to some management regime. In the definition of this constraint below, by means of the ***isexist*** set, the FORPRDEXIST variable is created only for those cohorts, region, land classes, owners, forest types, sites, management intensities, and simulation policies for which there is actually some land in the initial inventory:

```
sum(period,
      sum(isexist(period,cohort,reg,class,pvtlogowner,type,site,mgtintensity,policy),
FORPRDEXIST(period9999,cohort,reg,class,pvtlogowner,type,site,MgtIntensity,policy))
  =e=
  invent(cohort,reg,class,pvtlogowner,type,site,MgtIntensity);
```

where use of ***isexist*** limits attention only to potentially viable stands.

7.2.4 Forest management representation

Land management decisions for timberland owners simulated each period are: 1) whether to harvest a forest stand or keep it for another period; 2) whether to replant a harvested stand in trees (i.e., reforestation) or move it out of forest production (i.e., deforestation) converting it to developed or agricultural uses; 3) what forest type and timber management option to select if the land is planted in trees; and 4) what to do with the land if it is converted to agricultural use as will be discussed in the agricultural section below. These decisions are based on the relative profitability of land in its various competing alternative uses over the life-span of foreseeable choices.

FASOMGHG represents 23 alternative timber MIC regimes to depict potential responses to changes in policy or market conditions. These MICs represent silvicultural practices now being used or those that might be applied to future stands. MICs encompass the use of

- regeneration (natural or planted),
- stand density control (precommercial or commercial thinning),
- fertilization, and
- method of harvest (partial cutting, clearcutting or reserved from harvest).

MICs represent a regional average response for a particular forest type and site class. These MICs are initially populated with timberland inventory data as described later in Section xx.2, using guidelines from the 2000 RPA Timber Assessment (Haynes, 2003).

The basic way MICs appear in the forest sector model (excluding those dealing with harvest alternatives that are discussed in the harvest section just below) is portrayed in a simplified manner in table 7-5.

Table 7-5 Tableau depicting forest management intensity alternatives

	Manage stand with Passive MIC	Manage stand with Lo MIC	Manage stand with Higher MIC	Log demand	Total cost	
Timberland	1	1	1			= L
Harvested logs	$-ty_{passive}$	$-ty_{lo}$	$-ty_{higher}$	+1		= 0
Production cost		$+cst_{lo}$	$+cst_{higher}$		-1	= 0

Where

- L represents the initial inventory of land in the forest stand.
- $ty_{passive}$ is the log yield under use of the passive management alternative
- ty_{lo} is the log yield under use of the lo management alternative
- ty_{higher} is the log yield under use of the higher management alternative
- cst_{lo} is the cost incurred under use of the lo management alternative
- cst_{higher} is the cost incurred under use of the higher management alternative

The basic way MICs appear in the forest sector model (excluding those dealing with harvest alternatives that are discussed in the harvest section just below) is portrayed in a simplified manner in table 7-5.

Three variables represent these possibilities and are ***FORPRDEXIST(period,cohort,allreg,class,pvtlogowner,type,site,mgtintensity,policy)*** for existing stands, ***FORPRDNEW(period,when,allreg,class,pvtlogowner,type,site,mgtintensity,policy)*** for reforested stands and ***FORPRDNEWAFFOREST(periods,when,allreg,class,pvtlogowner,type,site,mgtintensity,policy)*** for afforested stands. Within these variables the ***mgtintensity*** dimension represents the MIC alternatives. The data giving yield differences are resident in the GAMS parameters ***existyld, newyld, existyldpc*** and n***ewyldpc*** as will be discussed in the section on stand growth below**.** The cost data are resident in the GAMS parameters ***existforestcost*** and ***newforestcost*** as discussed below.

7.2.5 Forest Establishment and Growing Costs

Cost estimates for stand establishment and intermediate treatments are resident in the parameters ***existforestcost(allperiods,cohort,allreg,class,type,mgtintensity,manage)*** and ***newforestcost(when,allreg,class,type,mgtintensity,manage)*** in the files ***data_forexistcost.gms*** and ***data_fornewcost.gms***, where the set ***when*** tells when management practices are applied relative to the date of planting. The ***manage*** set gives the alternative management cost items with the categories in that data being listed in table 7-6.

Table 7-6 Timber Management Costs

Cost category	Definition	Units
EST	Stand Establishment (site preparation and if applicable, planting and seedling costs)	2002 Dollars/acre
DEC	Decadal (aggregated periodic management costs including management plan, boundary maintenance, survey and cruising, and fire protection)	2002 Dollars/acre/Decade
HRB	Herbicide Treatment	2002 Dollars/acre
FRT	Fertilizer Treatment	2002 Dollars/acre
PCT	Precommercial Thinning	2002 Dollars/acre
RXF	Prescribed Fire	2002 Dollars/acre
Grow	Sum of Period Costs	2002 Dollars/acre

These cost estimates are included in the forest production cost equation that is defined as ***FORCOSTBAL(reg,period)*** by region and time period. The equation has terms that multiply these per acre costs times stand acreage and adds this up into the variable ***FORPRDCOST(reg,period)*** that in turn enters the objective function. The tableau in the previous section illustrates the way the cost data enter the model.

Terms were entered for costs associated with land use change for converting timberland to crop land or pasture land. Three levels of costs were used to represent a step function or increasing marginal costs of conversion as more timberland is converted. These data are resident in the parameter ***CONVERT(allreg,class,convdat,three)*** that is defined in the file ***data_forconvert.gms***. The convdat set has elements (1) ***ccost*** that gives the cost per acre converted, and (2) ***cquan*** that gives the maximum number of acres that can be converted at this cost. Note these data vary by land suitability for agricultural use and region. These data are entered directly into the objective function (***WELFAR***) and are applied to the land conversion variable ***LANDTOAG(reg,class,period,three)*** that tells how much acreage is converted from forest to agriculture by ***region,*** land suitability ***class,*** time ***period*** in each of the ***three*** steps**.** This will be further discussed and illustrated in the chapter below on intersectoral transfers.

7.2.6 Stand Growth

Harvest age is allowed to vary and thus the growth of existing and regenerated/afforested stands must be modeled. Timber growth and yield data are included for existing stands, reforested stands, and afforested lands that track the volume of wood in each unharvested stand which in turn is used in computing forest carbon sequestration. These data indicate the wood volume per acre in unharvested timber stands for each timber stand strata (e.g., a stand giving location, forest type, management intensity class, etc.) by age cohort. The data used are derived largely from the USDA Forest Service RPA modeling system (see Haynes (2003)).

Move next 2 paragraphs to data section?

More specifically, they are mostly based on yield tables resident in the ATLAS model (Mills and Kincaid 1992) version employed for the 2000 RPA Assessment, but are augmented with Pacific Northwest Westside timber yields developed by Alig et al. 2005 using the Forest Vegetation Simulator (Stage 1973).

Existing stand yield projections for each inventory cell are projected relative to a base yield, based on ATLAS estimates and a relative density approach described by Mills and Kincaid (1992). A set of base yield tables was derived for each forest type within each region from the FIA plot data. Moving from initial inventory estimates to future levels requires growth and yield estimates over time, which was also done by adopting ATLAS estimates (Mills and Kincaid 1992). These estimates add the dimension of time so that each aggregate is represented in every five-year period for 100 years. These data permit FASOMGHG to update the regional inventory levels by owner, land use suitability, forest type/species, site class, management regime, and age for each time period in the model. This general technique was used in past RPA Assessments (Mills and Kincaid 1992) and the use of empirical growth rates embodies the effects of historical and recent timber management and disturbances.

Once a cohort is harvested in FASOMGHG, the land can be regenerated. Regeneration yields are the potential yields for regenerated stands by region, land suitability class, owner, forest type, site class, management intensity class, and age cohort. Upon regeneration, FASOMGHG assigns a new MIC. Timber growth by MIC differs by region, forest type, site class, and age cohort.

Move next few paragraphs to data section?

Assumptions pertaining to initial stocking for a regenerated stand are based on the ATLAS modeling for the 2000 RPA Timber Assessment, and regeneration stocking ratios can differ by forest type, MIC, and site class (Mills and Kincaid, Haynes 2003). Stocking considerations also include "operational falldown," which took into account wind-damaged timber, breakage during harvesting, and other losses during management activities (Alig et al. 2005).

The ATLAS modeling process specifies no specific climate scenarios. Implicitly, all timber yields based on FIA field data incorporate past climate trends and this can affect future projections. Using scenarios to examine sensitivity of timber market projections to timber yield inputs, McCarl et al. (2001) analyze the impacts of different assumptions about yield effects from climate change.

For the Pacific Northwest west side, the FVS model was used to estimate timber yields, tapping into the same FIA data base as for the ATLAS-modeling. The FVS model draws upon FIA plot data and uses local growth rates to adjust model timber growth relationships. The FIA data provide a tree list, required for simulating an existing stand. Timber growth and yield predictions are dependent on interactions between trees within a timber stand. The FVS model can portray timber yields for a relatively wide variety of forest types and for both even-aged and partial cutting stand structures (Stage 1973).

The timber growth and yield data are in the GAMS parameters ***existyld(period,cohort,logregions,class,pvtlogowner,type,site,MgtIntensity,logproducts)*** and ***newyld(when,logregions,class,pvtlogowner,type,site,MgtIntensity,logproducts).*** The yield of harvested logs for stands that are thinned or partially cut are resident in ***existyldpc(period,cohort,logregions,class,pvtlogowner,type,site,MgtIntensity,logproducts)*** and ***newyldpc(when,logregions,class,pvtlogowner,type,site,MgtIntensity,logproducts).*** These data come from the files ***data_forexist.gms***, ***data_fornew.gms***, ***data_forexistpc.gms*** and ***data_fornewpc.gms***.

7.2.7 Harvest representation

The earlier version of FASOM used a forest inventory projection approach involving Johnson and Scheurman's (1977) "model II" with fixed yield relations that varied with management input. FASOMGHG still employs a model II structure for the even-aged portions of the forest, but also allows allocation of forest land to partial cutting or uneven-aged management regimes (using Johnson and Scheurman's "model I" scheme). This basic structure is portrayed in a simplified manner in table 7-7.

Table 7-7 Tableau depicting forest clearcut harvesting alternatives

	Clearcut in T_1	Clearcut in T_2	Clearcut in T_3	Clearcut in T_4	Clearcut in T_3 with thin in T_1	Clearcut in T_4 with thin in T_1	Partial cut in T_1 and T_3	Log demand	
Timberland	1	1	1	1	1	1	1		= L
Harvested Logs in T_1	$-cc_1$				$-th_1$	$-th_1$	$-pc_1$	+	=0
Harvested Logs in T_2		$-cc_2$						+	=0
Harvested Logs in T_3			$-cc_3$		$-ct_3$		$-pc_3$	+	=0
Harvested Logs in T_4				$-cc_4$		$-ct_4$		+	=0

where

- T_n represents time period n and indexes five year periods.
- L represents the land in the forest stand.
- cc_n is the yield obtain from a clearcut operation in time period n
- th_n is the yield obtained from thinning operations in time period n
- ct_n is the yield obtained from a clearcut operation in time period n on a stand that was previously thinned
- pc_n is the yield obtained from a partial cutting harvest operation in time period n.

The table columns broadly depict the harvest alternatives which are clearcut, thin then clearcut and partial cut (which can also be combined with a clearcut). The first four variables show harvest age alternatives for a clearcut. The data in cc_n arises from the timber growth and yield tables and would reveal an increasing volume of growth as harvest is delayed. The fifth and sixth variables show thinning combined with clearcut where ct_n would differ from cc_n because of the effects of thinning. The last harvest variable shows a partial cutting regime which yields periodic harvested logs pc_n but is not in general clearcut at the end. More on the harvest alternatives is given in the sub sections just below.

Three variables represent these possibilities and are ***FORPRDEXIST(period,cohort,allreg,class,pvtlogowner,type,site,mgtintensity,policy)*** for existing stands, ***FORPRDNEW(period,when,allreg,class,pvtlogowner,type,site,mgtintensity,policy)*** for reforested stands and ***FORPRDNEWAFFOREST(periods,when,allreg,class,pvtlogowner,type,site,mgtintensity,policy)*** for afforested stands.

Within these variables the ***period*** dimension of the ***FORPRDEXIST*** variable gives harvest time and could include a never case. Simarly the ***when*** dimension of the ***FORPRDNEW*** and ***FORPRDNEWAFFOREST*** variables depicts harvest age (being plus25, plus30, plus35, … never).

7.2.7.1 Even-aged Timber Management

In representing even-aged management, FASOMGHG assumes all of the trees in a stand are removed when clearcutting, and in turn allocates all of the growing space to subsequent regeneration or land use change. In all forest regions, there are at least two even-aged MIC alternatives for regenerated aggregates. These include the ***passive*** and ***lo*** alternatives.

The ***passive*** MIC refers to a stand that receives little management intervention of any kind between harvests of naturally regenerated trees. A ***lo*** MIC refers to custodial management (where timberland receives management such as forest protection and elimination of grazing by livestock) of naturally regenerated trees. Additional MICs are present in the SC, SE, and PNWW, representing stand establishment and intermediate management, followed by a clearcut final harvest. In addition to final harvests, commercial thinnings can occur. A relatively intensive example of an even-aged MIC for the South would involve site preparation and establishment of a pine plantation using genetically-improved tree stock, commercially thinning in later years, and then final harvest at ages beyond 20 years of age. A mathematical description for an even-aged scheduling structure is given by Adams et al. (1996), emphasizing the forest sector and illustrating the interperiod link of existing, new or regenerated, and terminal timber stands.

Move? The passive MIC was added to the ATLAS-based MICs to represent cases where the landowner accepts whatever type and rate of regeneration occurs naturally (Adams et al. 1996), modeled as growing under even-aged conditions. Relative to the lo MIC, where timberland receives a low level of timber management, such as forest protection and elimination of grazing by livestock, future merchantable timber yields for the passive MIC are lagged ten years and reduced 10% relative to those for low MIC timber yields for that same region, forest type, and site class.

7.2.7.2 Partial cutting timber management

In modeling timber management by partial cutting, we broadly represent the periodic removal of mature trees, leaving immature trees to grow, thereby allocating a portion of the growing space to regeneration but none to land use change unless a terminal clearcut is chosen. In contrast, we assume removal of all trees when harvesting an even-aged stand with all of growing space reallocated to regeneration or land use change. We model regimes of multiple-entry partial harvests over long time periods.

Partial cutting MICs are represented in the SE, SC and PNWW regions. In the SC and SE regions, partial cutting takes place in four forest types: natural pine, oak-pine, upland hardwood, and bottomland hardwood. The partial cutting MICs for the region include low, high, and high-plus regimes. In the PNWW, partial cutting MICs are represented for the Douglas-fir and Other Softwood types.

7.2.7.3 Minimum harvest age

Minimum harvest age restrictions are used to represent lower limits of merchantablity of stands, ages below which there is insufficient merchantable volume ina stand to justify commercial entry. Eliminating activites for stands below the minimum harvest age also helps to reduce model size, since timber harvesting isnot allowed and the generation of a number of variables is suppressed. They are based on observations of merchantable age thresholds drawn from the ATLAS inputs used in the 2000 RPA Timber Assessment (Haynes 2003). Minimum harvest ages vary by region, owner, site class, forest type, and MIC. The original data appear in the ***minharv2(allreg,allowner,type,mgtintensity,site)*** GAMS parameter in the ***data_forminiharv.gms*** file.

7.2.8 Reforestation, Afforestation and Deforestation

When timber on existing even-aged forested lands is harvested, all trees are assumed to be removed and the resultant treeless bare land may be either:

- reforested
- transferred to agriculture
- transferred to a developed use.

In addition, in any period land may be transferred in from agriculture and afforested. This is controlled within the ***FORLANDBALANCE(reg,class,pvtlogowner,successorgroup,site,period)*** equation. In each five-year period, potentially reforestable acres (in the ***FORPRDNEW*** variable) plus timberland transferred out to agriculture (in the ***CONVRTTOAG*** variable) or development are balanced (in the ***regdevelopmentfor*** data) with the land available from timber harvest arising from existing, reforested, and afforested stands(respectively in the ***FORPRDEXIST, FORPRDNEW*** and ***FORPRDNEWAFFOREST*** variables). Similarly, potentially afforested acres (in the ***FORPRDNEWAFFOREST*** variable*)* are balanced with lands in-migrating from agriculture (in the ***CONVRTTOAG)***. When timberland is reforested or afforested, the model selects an MIC and an optimal future harvest date. These acres are then retained in the forest base until their harvest date, at which time another reforestation or land use decision is made.

Afforestation activity is assumed to only occur for nonindustrial private ownerships and only into the medium and high site classes. Consistent with other studies and long-term trends (see Haynes, 2003, for a discussion of these trends), we also assume that there will be little or no loss of industrial land to non-forest developemtn. Thus, the timberland area for forest industry in the FASOMGHG modeling is assumed to remain constant in the baseline case, by region over the projection period. That is, all forest industry timberland is placed in the "***FORONLY***" land suitability class, where it remains over the projection.

Decisions regarding the characteristics and timing of private areas afforested, reforested, or converted to agricultural use are endogenous. The choice of investment levels in intermediate treatments or timber management are also consistent with a wealth-maximizing objective, in contrast to external determination of management investment decisions as in most past studies (e.g., Haynes 2003).

Table 7-8 Tableau depicting afforestation, reforestation and deforestation

	Clearcut Exist Stand in T1	Clearcut Exist Stand in T1+k	Reforest Land in T1 then Clearcut in T1+k	Reforest Land in T1+k then Clearcut in T1+2k	Afforest Land in T1 then Clearcut in T1+k	Land from Ag in T1	Land to Ag in T1	Log demand	Ag activity in year T_1	
Exist Timberland	1	1								= L
Bare land in T_1	-1		1				1			= $-dev_1$
Bare land from ag in T_1					1	-1				= 0
Bare land in T_{1+k}		-1	-1	1	-1					= $-dev_{1+k}$
Harvested Logs in T_1	$-he_1$							+		=0
Harvested Logs in T_{1+k}		$-he_{1+k}$	$-hr_{1+k}$		$-ha_{1+k}$			+		=0
Ag land in T_1						1	-1		+	=A

where

T_n -- represents time period n and indexes the five year periods.
K -- is the rotation age for new stands (note this is fixed only for display purposes)
L -- represents the initial inventory of lands in existing forest stands.
he_n -- is the yield obtained from a clearcut operation on an existing stand in time period n
hr_n -- is the yield obtained from a clearcut operation on a reforested stand in time period n
ha_n -- is the yield obtained from a clearcut operation on afforested stand in time period n
A -- is available agricultural land
dev_n -- is the private NIPF land moving to developed use in time period n

The columns in table 7-8 broadly depict the variables and associated equations for production and harvest of existing, reforested, and afforested stands. The first two variables (representing the variable ***FORPRDEXIST***) allow choice of varying harvest ages for clearcut of existing stands. The first constraint restricts the use of the existing stands to the available inventory.

The next two variables represent reforestation activity (the model variable ***FORPRDNEW***). The first of these depicts reforestation in the first time period with subsequent harvest k time periods later. Note that such early reforestation can only follow harvested existing stands. The second reforestation variable represents the possibility for reforestation of land after a previous forest rotation in a time period (T_{1+k}) long enough after the model starts that initially reforested stands have enough time to become mature and eligible for harvest. This reforestation activity (that in T_{1+k}) can follow after existing, reforested, and afforested stands. Reforestation activity following existing stands must remain unharvested up until the time period at issue (1+k in this case). When reforestation activity (that in T_{1+k}) follows a previously reforested stand (i.e., one from T_1), the preceding reforested stand has to have been endogenously planted or naturally regenerated in an earlier model time period and have achieved sufficient maturity to make it eligible for harvest by the time period at question. When reforestation activity follows an afforested stand, it must have the same characteristics in terms of being planted earlier and now being eligible for harvest as mentioned above when following a reforested stand, but can only be placed on land moving over from agriculture in the time period at question as imposed by the third constraint.

The fifth variable in the tableau depicts afforestation (in the model variable ***FORPRDNEWAFFOREST***). This variable is only defined for the first tree planting rotation after land moves over from agriculture. The variable requires land coming from agriculture and upon harvest puts land into the same category as any other harvested stand becoming eligible for subsequent reforestation.

The sequencing relationships, in terms of enforcing what stands other stands can follow, are represented by the second and third equations in the tableau. In the GAMS implementation this is the ***FORLANDBALANCE*** equation. That equation also requires that land be harvested and diverted to developed uses.

The final four equations depict land moving to and from agriculture, wood product processing/demand, and agricultural land use and will be discussed below.

7.2.8.1 Species succession

One feature of the rotation aspects of reforestation involves species succession. We restrict reforestation activity so that only certain species can succeed other species. This prevents the model from having for example upland hardwood succeed bottomland hardwoods. Currently a restriction is in place that only allows the same forest type to succeed the original forest type. In the longer run this will be relaxed.

7.2.8.2 Developed use

Exogenous data on movement of forested land to developed uses were included to account for timberland converted to development. Deforestation for the purpose of development (e.g., urban use of land) is handled by exogenous land transfers out of forestry. Projections were obtained from land use modeling for the 2000 Resources Planning Act (RPA) Timber Assessment (Alig et al. 2003, Haynes 2003) and updated to reflect current development estimates (Alig et al. 2004). A key part of the development projections are expected changes for population and personal income by state (Alig et al. 2004).

7.2.9 Wood products

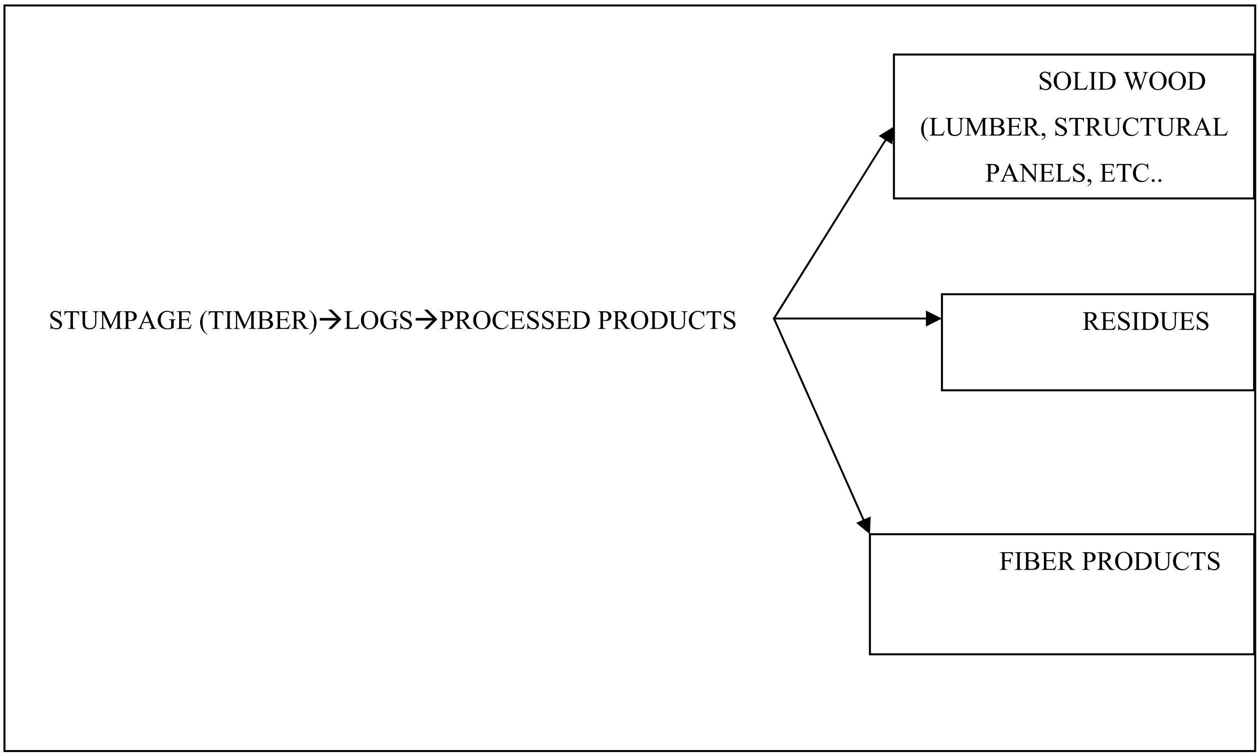
Earlier versions of FASOM and essentially all past dynamic models of the forest sector (Johnson and Scheurman, 1977; Berck, 1979; Sedjo and Lyon (1990), Adams et al (1996), Sohngen et al, 1999; Shillinger et al, 2003) have used a single market level formulation, the markets for logs, with a single demand region, multiple supply regions, and limited differentiation between types of products and species. These approaches were computationally tractable and required relatively limited data to calibrate, but it was difficult to use them to model the impact of changes in product trade, trade restrictions or exchange rates; shifts in determinants of demand for processed products (such as housing activity or GDP growth); or changes in the technology of wood products processing. Accounting for carbon stored in product pools was also cumbersome in these models, requiring fixed assumptions about log breakdown into specific product proportions regardless of log prices or changes in the log market.

FASOMGHG overcomes many of these difficulties by incorporating multiple market levels in the forest sector (logs, intermediate products and final products) in the form of a manufacturing sector that transforms logs and their intermediate products into final products. It explicitly includes such manufacturing in both the US an Canada (the US's principal wood products trading partner). Harvest of an acre of timberland involves the simultaneous production of some mix of softwood and hardwood logs (sawlogs, pulpwood, and fuelwood; see glossary). The composition of this product mix varies across regions, site classes, forest types, and age cohorts and changes over time as stands age. Proportions also change between MICs.

Downward substitution of logs is allowed. Sawlogs can be substituted for pulpwood, and pulpwood, in turn, can be substituted for fuelwood, provided that the prices of sawlogs and pulpwood, respectively, fall to low enough levels. This "down grading" or inter-product substitution is technically realistic and prevents the price of pulpwood from rising above that of sawlogs and the price of fuelwood from rising above that of pulpwood.

Logs in turn are processed into products. The full sequence of transformations from trees to products is illustrated in Figure 7-1.

Figure 7-1. Flows of wood and products in forest sector of FASOMGHG.



With this additional market and product detail, the forest sector includes a full materials balance, accounting for all wood flows from forest to final products.

7.2.9.1 Log and solid wood products

Table 7-9 lists the classes of harvested logs and wood products at the mill represented in FASOMGHG. Harvested logs are identified as either softwood or hardwood species and as sawtimber, pulpwood or fuelwood. Sawtimber is processed into one of the solid wood products, with the exception of OSB (oriented strandboard) which is classified as a structural panel but uses pulpwood as its fiber source. Quantities and prices of lumber, softwood plywood and OSB are determined endogenously in the model. Demands for, and production of, hardwood plywood, other nonstructural panels and miscellaneous products are determined outside the model. Two classes of residue by-products are produced by solid wood products milling and may be transferred to pulping, used as fuel, or left unutilized. Product classification and treatment in the solid wood sector follow the TAMM model format (Adams and Haynes, 1996).

Table 7-9 Classes of forest sector products by market level and processing sector

Timber and Logs	Solid Wood Products	Fiber Products
Softwood sawtimber	Using Sawtimber	Recycled fiber
Softwood pulpwood	Softwood lumber	Old newspapers
Softwood fuelwood	Softwood plywood	Old corrugated
Hardwood sawtimber	Hardwood lumber	Wastepaper (mixed)
Hardwood pulpwood		Pulp substitute
Hardwood fuelwood	Using Pulpwood	High quality deinking
	OSB	
		Primary Products
	By-products	Newsprint
	Softwood residues	Uncoated freesheet
	Hardwood residues	Coated freesheet
		Uncoated groundwood
		Coated groundwood
	Exogenous Products	Tissue
	Hardwood plywood	Specialty packaging
	Nonstructural panels	Kraft packaging
	Miscellaneous products	Linerboard
		Corrugating medium
		Special bleachedboard
		Recycled board
		Construction paper
		Dissolving pulp
		Market pulps
		Softwood kraft market pulp
		Hardwood kraft market pulp
		Recycled chemi-mechanical pulp
		CTMP pulp

Note: production and consumption volumes of “exogenous” products are determined outside the model. All other volumes determined by market simulation within the model.

7.2.9.2 Pulp and fiber products

In the fiber products sector, supplies of recycled fiber are classed in five groups. Old newsprint, old corrugated containers and mixed wastepaper generally originate at consumption or distribution points. High quality deinking and pulp substitutes arise from printing plants and box/container makers. Fourteen classes of primary paper and paperboard products are identified, including a dissolving pulp category (used in photographic film and fabric production). The model also employs four classes of market pulps varying with the pulping process and fiber input mix. All of the primary product quantities and prices are determined endogenously in the model. Product classification and treatment in the fiber products sector follow the NAPAP model format (Zhang et al, 1993; Ince, 1994).

7.2.10 Log and intermediate processing

Wood product manufacture is explicitly modeled. Figure 7-2 illustrates the flows of wood from forest to manufacture. The inventory accounting at the far left relates exclusively to the growing stock volume that is measured in the basic FIA inventory data (see preceding sections for a discussion of the inventory data). The non-growing stock volumes are estimated as proportions of the total wood volume used in processing (regardless of source) on a product-specific basis. The split into solidwood, pulpwood and fuelwood is consistent with the product composition of the timber inventory (sawtimber, pulpwood and fuelwood). As noted above, logs can also be "downgraded" to the next most valuable use: so sawlogs can be used as pulpwood and pulpwood as fuelwood. Output in product units at the far right side of the diagram is computed by means of fixed product conversion coefficients (product units/unit of wood input). The residue/roundwood mix shown for pulp products is determined by the wood requirements of the available pulping processes and the relative values of residue used in pulping and energy generation.

Processing is represented via the variable ***FORWDMANUFACT(period,activewoodregions,woodproduct,process,inputmix)*** that represents manufacture of a particular ***woodproduct*** via a particular ***process*** using a particular mix of intermediate products or logs (***inputmix)*** in a ***region*** during a time ***period***. Input requirements in terms of intermediate products and logs are given in table ***woodmancoefs(activewoodregions,woodproducts2,woodproduct,Process,inputmix,period)*** which tells how much of each of the other products (***woodproducts2***) are used to manufacture one unit of a specific ***woodproduct*** in a specific region (***activewoodregions)*** via the technology mix ***(Process,inputmix).*** These production conditions can vary with time period. The data are specified in the file ***data_formcoefs.gms***. The log, intermediate and final products are controlled by balance equatios so use cannot exceed supply in the constraint ***FORWDBALANCE***. In addition, residues are accounted for in the constraint ***FORWDRESIDUES(activewoodregions,residues,period)*** and recycled paper in the equation ***FORWDRECSUPPLY(activewoodregions,woodproducts,period)***.

Manufacturing is also subject to the capacity constraints ***FORWDCAPACITY(activewoodregions,woodproducts,process,period)*** that are defined by ***region, product*** and ***process*** in a ***period.*** The capacity data are in the GAMS parameter ***woodcap(activewoodregions,woodproducts,process,period)*** which are input via the file ***data_forcapacity.gms***.

Figure 7-2. Wood flows in the forest sector of FASOMGHG.

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The tableau in table 7-10 summarizes the treatment and disposition of wood and product volumes in the forest sector of FASOMGHG.

Table 7-10 Tableau depicting treatment and disposition of wood products

	Stand harvest	Sawlogs to mill	Pulpwood logs to mill	Downgrade sawlogs to pulpwood	Manufacture lumber	Manufacture Plywood	Chip a pulpwood log	Make paper from chips and recycled fiber	Make OSB from chips	Move residue into pulpwood	Non-wood input	Sell products	
Welfare	-										-nwc	+	
Harvested sawlog balance	-	+1											= 0
Harvested pulpwood log balance	-		+1										= 0
Mill sawlog balance		-1		+1	+sls	+slp				+			= public sawlogs
Mill pulpwood log balance			-1	-1			+1						= public pulpwood
Lumber balance					-1							+	= 0
Plywood balance						-1						+	= 0
OSB balance									-1			+	= 0
Paper product balance								-1				+	= 0
Chipped log balance							-yp	+pr	+po	-1			= 0
Recycled fiber balance								+pf				-	= 0
Milling residues balance					-yrs	-yrp				+1			= 0
Paper manufacturing capacity								+1					≤ capacity
Sawlog harvest and haul non-wood input		+1									-		= 0
Pulplog harvest and haul non-wood input			+1								-		= 0
Paper non-wood input								+1			-		= 0

where

nwc	is the non-wood input function for log hauling and paper manufacture
sls	is the use of saw logs to manufacture one unit of saw timber
slp	is the use of saw logs to manufacture one unit of plywood
psl	is the exogenous supply of public and other saw logs
ppl	is the exogenous supply of public and other pulp logs
yp	is the yield of wood chips from one unit of pulp logs
pr	is the use of wood chips to manufacture one unit of paper
pf	is the use of recycled fiber to manufacture one unit of paper
po	is the use of wood chips to manufacture one unit of OSB
yrs	is the use of milling reside when manufacturing one unit of saw timber
yrp	is the use of milling reside when manufacturing one unit of ply wood
cap	is paper making capacity

The columns in the table broadly depict the variables and associated equations for wood products manufacturing and log downgrading. The first variable represents forest harvest and the output of harvested logs as discussed above. All of the remaining variables except the last two reflect activities at wood products manufacturing facilities and are represented in the variable ***FORWDMANUFACT(period,region,woodproduct,process,inputmix)*** of the GAMS implementation. Such variables indicate the level of manufacturing related activity during a ***period*** by ***region*** in terms of the number of units of a particular wood product (***woodproduct)*** being made with a particular ***process*** and ***input mix***.

Several aspects of the model are illustrated in this tableau.

- There is a distinction made between logs in the woods and logs at the manufacturing facility. This is done through use of a variable within the manufacturing portion of the model that reflects transformation of logs with status (location) “in the woods” to logs with status “at the mill”.
- The log to manufacturing facility transformation also uses non-wood inputs for harvesting and hauling. These are grouped under the non-wood input portion of the model in the GAMS implementation variable ***FORWDNWCS(woodsupplytype,activewoodregions,woodproducts,period9999,steps)*** that in general depict an upward sloping supply function for such non-wood inputs.
- FASOMGHG includes the potential for downgrading logs. In the example tableau the variable Downgrade sawlogs to pulpwood shows transformation of sawlogs into pulpwood logs. This will only be done when the value of the sawlogs has been driven down to equal the value of the pulpwood logs.
- When solid wood products like lumber and plywood are made, then one obtains the byproduct milling residues.

- Some products are transformed within the model. For example pulpwood logs are converted into chips in the Chip pulpwood variable.
- Milling residues can be substituted for pulpwood and in turn go into the paper or OSB manufacturing processes.
- Competing uses are reflected for alternative inputs. For example, in the tableau sawlogs can go into either lumber or plywood manufacture while the chips from pulpwood logs can go into either a pulp and paper operation or OSB manufacture.
- Manufacturing activities in general use non-wood inputs and incur costs.
- Manufacturing activities are potentially subject to capacity constraints.
- Manufacturing capacity is accounted by processing alternatives across all input mixes.
- The non-wood inputs differ by process and input mix.
- Paper does not have non-wood inputs that vary with output volume rather they are constant on a per unit basis.
- Alternative processes and input mixes can be used as illustrated in table 7-11 that depicts an example for paper. This tableau shows two processes for making paper from wood chips (roundwood and residues) and recycled fibers each having two alternatives involving different mixes of inputs.
- Total chip supply comprises chipped pulpwood logs and residues generated in the manufacture of solid wood products.
- OSB competes with fiber products (paper) for chips.
- Capacity is reckoned at the process level, since a given process can be adapted to either of the input mixes.

Table 7-11 Tableau illustrating alternative processes and input mixes in the case of paper

	Manufacture lumber	Manufacture Plywood	Chip a pulpwood log	Make paper from chips and recycled fiber process 1, input mix A	Make paper from chips and recycled fiber process 1, input mix B	Make paper from chips and recycled fiber process 2, input mix AA	Make paper from chips and recycled fiber process 2, input mix BB	Make OSB from chips	Move residue into pulpwood	Non-wood input	Sell products	
Paper products				-1	-1	-1	-1				+	= 0
Chipped logs			-yp	+pr1a	+pr1b	+pr2aa	+pr2bb	+po	-1			= 0
Recycled fiber				+pf1a	+pf1b	+pf2aa	+pf2bb				-	= 0
Milling residues	-yrs	-yrp							+1			= 0
Paper capacity process 1				+1	+1							≤ capacity 1
Paper capacity process 2						+1	+1					≤ capacity 2
Paper non-wood inputs				-pc1a	-pc1b	-pc2aa	-pc2bb			1		= 0

7.2.11 Harvest, hauling and processing costs

The fiber products sector, drawn from NAPAP, is modeled exclusively as a fixed coefficients production process. Total production costs for any given product can be computed as the sum across all inputs (factor use per unit of product output times the cost per unit of factor) times the level of output. There are no factors whose unit costs vary with the volume consumed or whose use per unit of output is not constant. In the solidwood sector, drawn from TAMM, output is assumed to be a fixed multiple of wood input, but the relationship between output and non-wood inputs varies with the level of output. Assuming quasi-fixed capital inputs, the production function for a specific product would appear as:

NEED EQUATION NUMBERS

$$Q = \min[r_W W, f(X_1, X_2, \ldots, X_n, K)]$$

Where

Q is output
r_w is the product recovery factor for wood (output per unit input or $Q = r_w W$)
W is the volume of wood input
X_i are the non-wood variable inputs, and
K is quasi-fixed capital.

The function f can be viewed as an aggregator function for the other inputs, and the two groups of factors, W and (X_i, K) are weakly separable. In this case, *and assuming that the aggregator function (f) can be approximated by a quadratic form*, it can be shown that the inverse (price-dependent) product supply curve can be written as:

$$P = F(Q, K) + (1/r_w)P_w$$

where

P is product price
P_w is wood input price, and
F(Q, K) is a linear function of output, quasi-fixed capital and the prices of all other inputs.

As a result, the area under the product supply curve (total variable costs) can be shown to be: $\int P dQ = \int F(Q,K) dQ + \int P_W dW$ where the first term on the right side is the total variable cost arising from use of the non-wood inputs and the second term is the area under the timber or log supply curve. The first term is called "non-wood input" in TAMM (and FASOMGHG) as shown in equation [7._] above. It includes all non-wood inputs to log processing at the mill (labor, energy, and other) and all harvest and transport costs from woods to mill. The second term on the right is the cost of timber and is represented in the model objective by the "management cost" terms in equation [7.__].

Coefficients for the non-wood input equations are found in the GAMS data item **WOODnwcost(WOODsdtype,allreg,alli,allperiods,params)** in the FASOMGHG input file **data_forsupdem.gms**. Non-wood input equations vary by product (**WOODsdtype**) region (**allreg**) and period. Total non-wood inputs are computed in the FASOMGHG constraint ***FORWDNWCEQ(woodsupplytype,allreg,alli,allperiods).***

7.2.12 Other sources of log supply

Not all of the timber harvest and logs in the model are generated from the private land inventory and harvesting process. Exogenous supplies come from National Forests and other public timberlands in the US and, in Canada harvests from provincial and private lands are represented by price-sensitive supply relations

7.2.12.1 US Public log supplies

Harvests of logs from public lands in the US are treated as exogenous in FASOMGHG. Policies that determine harvests on these lands are based on an array of public and environmental concerns and generally do not consider prices or developments in log and product markets. These volumes are incorporated in the input file ***data_forlogsupdem.gms*** in the GAMS data item ***WOODlogsup(WOODsdtype,allreg,allowner,alli,allperiods,params)***

US public harvests are the intercept terms (***params***) for the appropriate region and owner (***NF*** or ***OG***). In the model solution process these preset volumes are transferred in each period to the variable ***FORWDSUPPLY(woodsupplytype,allreg,alli,allperiods)*** in the equation ***FORWDLOGSUPEQ(woodsupplytype,activewoodregions,allowner,woodproducts,period9999)***

7.2.12.2 Canadian log supplies

Log supplies in Canada derive primarily from public lands (termed "Crown" lands) governed by the individual provinces with a small volume coming from private lands. Harvests may vary over time based on extraction and delivery costs and hence with market log prices. These supplies are represented by a set of (log price sensitive) delivered log supply equations for both sawlogs and pulpwood. The supply equation coefficients are input through the same files and variables as the US public supplies described above. The area under the Canadian log supply curves are deducted from the overall model objective function. The actual current period harvest volumes from Canadian forests are computed in the equation ***FORWDLOGSUPEQ(woodsupplytype,activewoodregions,allowner,woodproducts,period9999)*** by summing the volumes linked to the active steps included in the current period solution.

7.2.12.3 Other log supply

Small volumes of logs are also imported to the US for processing from Canadian and non-Canadian sources. These volumes are treated as exogenous in FASOMGHG. They also enter the model via the ***data_forlogsupdem.gms*** in the same table as the other supplies discussed above.

7.2.13 Wood product movement and markets

FASOMGHG permits interregional commodity movements for certain commodities in certain directions using the variable ***FORWDTRANSPORT(activewoodregions2,activewoodregions,woodproduct,period)*** that depicts movement of a particular product (***woodproduct)*** between a source region ***(activewoodregions2)*** and a destination region ***(activewoodregions)*** during a time ***period***. Such movements are restricted on a bilateral and product flow basis to ensure that model behavior does not drift too far from historically observed product flow patterns.[4] Notes on the types of restrictions imposed appear in the sections just below.

The data defining when flows are allowed are resident in the data in the parameter ***woodtranscost(activewoodregions2,activewoodregions,woodproducts).*** Shipments are only allowed when the woodtranscost data are non zero. The movement variable incurs costs in the objective function ***(WELFAR)*** and uses commodities within the ***FORWDBALANCE(activewoodregions,woodproducts,period)*** equation**.**

7.2.13.1 Logs and residues

With certain exceptions, logs are not permitted to flow between regions. Because logs are expensive to transport, actual interregional log flows are relatively limited. Where larger flows are observed, the volumes originate near the borders of regions and move to immediately adjacent border areas in other regions. We rule out most of these flows to maintain better control of regional production (and harvest) behavior. The cases excepted include shipments of hardwood pulpwood and other logs from northern US regions to eastern Canada and hardwood log shipments from the east to the PSW region for both processing and export. Residues are also permitted to move from the northern US into eastern Canada.

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[4] For an extensive discussion of problems in tracking bilateral trade flows between regions in the forest sector and potential solutions see Kallio, Dykstra and Binkley (1987).

7.2.14 International trade

Wood product sector trade modeling is handled differentially depending on whether the trade is with Canada or with other countries.

7.2.14.1 Canada

Canadian demand and supply regions are included but we do not attempt to model bilateral trade flows with the US in both directions. The model uses only a single US and Canadian national demand region for wood products. Product movements from Canadian producing regions to the US demand center are endogenous and subject to appropriate transport costs, exchange rates and tariffs. Solid wood demand in Canada is treated as exogenous and varies over time according to projections in the 2000 RPA Timber Assessment (Haynes, 2003). Solid wood exports from the US to Canada are exogenous. Fiber products demand in Canada is price sensitive but fiber products exports from the US to Canada are treated as exogenous. Tariffs are set at "current" (2003) levels. The projected Canadian-US exchange rate (a real rate since the model employs deflated prices for all goods) also follows trends in the 2000 RPA Timber Assessment.

7.2.14.2 Other regions

With the exception of US imports of softwood lumber, the Canadian and US regions are modeled so that they trade wood products with other world regions. This trade is specified as exogenous regionally-specific volumes. Base case projections follow trends in the 2000 RPA Timber Assessment. Data are entered via the GAMS data array ***WOODsupdem(WOODsdtype,allreg,alli,allperiods,params)*** in the file ***Data_forsupdem.gms***.

Softwood lumber imports into the US from non-Canadian sources are based on an import supply function drawn from the 2000 RPA Timber Assessment (Haynes 2003). The function shifts over time according to the base scenario in the Timber Assessment. Slope and intercepts for the linear functions are entered via ***WOODsupdem(WOODsdtype,allreg,alli,allperiods,params)*** in the file ***Data_forsupdem.gms***.

7.2.15 Wood product prices

FASOMGHG incorporates price dependent demand relations for softwood lumber, softwood plywood, hardwood lumber, OSB and a number of fiber products. The relations for non-fiber products were derived by aggregating TAMM annual demand relations. Demand relations for the 14 classes of primary fiber products were derived from NAPAP.

The basic set of FASOMGHG relations comes from the TAMM-NAPAP "base case" as described in the 2000 RPA Timber Assessment (Haynes, 2003). The solidwood demand relations are linear, except for hardwood lumber that uses a constant elasticity form. All of the fiber products demand curves are of the constant elasticity form. These curves shift over time following the TAMM and NAPAP procedures. Alternative projection scenarios that would influence the intertemporal development of demand (e.g., changes in the projections of macroeconomic activity or price trends of substitute goods) require re-derivation of the FASOMGHG demand curves by making an appropriate TAMM-NAPAP run and extracting then reaggregating new demand relations.

The demand curves for the final consumption of timber products are incorporated into FASOMGHG at a national level. In addition, the forest manufacturing sector utilizes many products as intermediate inputs all on a regional basis. Similarly both international and interregional trade are specified on a regional basis. FASOMGHG thus generates wood product prices at both the regional and national levels. Goods flow from regions into national demand at a cost equal to the historically observed price difference. This is done within the ***FORWDTRANSPORT*** variable.

7.2.16 Price expectations

FASOMGHG incorporates the multi-period path of future prices. Farmers and timberland owners are able to foresee the consequences of their behavior (when they plant trees or crops) on future stumpage and agricultural product prices and incorporate that information into their behavior. The FASOMGHG model uses deterministic expectations, or "perfect foresight", whereby expected future prices and the prices that are realized in the future are identical.

7.2.17 Timing issues

FASOMGHG is fundamentally designed to simulate forest and agricultural sector activity over time. Thus, it must have a dynamic representation. In particular, it was judged essential that FASOMGHG reflect the substantial time lag between the establishment of a timber stand and its harvest. In addition the GHG consequences of pursuing certain types of forestry actions differ over time and thus are dynamic. As a consequence FASOMGHG is designed to depict activity over a long time period, approaching 100 years in its current form.

A related issue is the number of explicit time periods that should be reflected within this total 100 year horizon. In the original FASOM version (Adams et al. 1996), time was represented in ten year intervals. Experience with subsequent model analysis sometimes suggested that ten year intervals were too long. This was particularly true in terms of harvest rotations in the South which can be as short as 20 years. Restricting rotations to ten year intervals like 20 or 30 or 40 years was constraining. As a consequence FASOMGHG is set up based on a five year time step allowing portrayal of Southern harvest options at 20, 25 and 30 year periods Naturally there is a trade-off in the model between the number of explicit time periods (given a 100-year projection period) and model size.

Forestry activities are assumed identical in each year of a five year period as are activities in forest manufacturing and harvest. These cases were treated as if they generated constant costs and returns during each year of a five year period. The only exception is that certain forestry costs that occur only once during a rotation, e.g., regeneration costs, were not annualized.

7.2.17.1 Annuities and time periods

The forestry model returns and costs are assumed to represent typical activity during each year of a five year period (running from year 0 to year 4). Thus, forest returns in each explicit period were treated as a continuing annual series of five equal amounts discounted to the start of each period under the assumption that the same level of returns arise in each year of the period. In the terminal period returns arising in all subsequent years (beyond the end of the projection) were treated as an infinite annuity as will be discussed in the next section. Thus the period specific annuity factor d_p

$$d_p = \sum_{t=0}^{4} \frac{1}{(1+r)^t} \quad \text{for} \quad 0 \le p \le P-1$$

and

$$d_p = \frac{1}{r} \quad \text{for} \quad p = 9999$$

Where

r is the discount rate for period p as defined in the GAMS parameter ***discrate*** in ***data_basicsets.gms*** and typically reset in the file ***model_structure.gms***
P is the last time period plus one as is defined in the set called ***period9999*** in ***data_basicsets.gms*** and may be reset in the file ***model_structure.gms***.

In turn, the forestry part of the objective function is

$$W = \sum_{p=0}^{P} \frac{1}{(1+r)^{5p}} \; d_p \; ForWel_p$$

where

W is the net present value of forestry welfare.
d_p is the period specific annuity factor which is contained in the model in the array ***Annuitywt(periods,"forestry")*** as computed at the top of the ***model_structure.gms*** file.
p identifies the five year time period.
$ForWel_p$ represents the multi term forestry consumers' and producers' surplus objective function in multi year time period p.

The term involving (1+r) exponentiated to the 5p provides a discount factor to take the net present value of the returns in each time period back to the first model period. Multiplying by period-specific annuity factor d_p converts the returns in each five year period to net present value in the dollars of the first year in each period. All of this is implemented in the ***WELFAR*** equation within the file ***model_structure.gms***

7.2.17.2 Discounting forestry returns after the projection period

Values arising in the forest sector beyond the terminal period are handled as an annuity. Harvest volumes are computed using von Mantel's formula as discussed below. Discounted net surpluses from this harvest are computed at the end of the final model projection period (using the standard form for the present value of an infinite annual payment, 1/r). The end of projection values are then discounted to the start of the projection.

7.2.18 Markets over time

FASOMGHG reflects changes over time in market and production conditions. In the forest sector, changes in basic projection conditions are all-time based and specified outside of the model. Demand relations for solid wood and fiber products shift over time, based on TAMM and NAPAP projections (see Chapter 2) for a specific RPA case. For the FASOMGHG base case and many of the alternative GHG policy analyses, we employ the 2000 RPA Timber Assessment BASE case (Haynes, 2003). Other RPA scenarios can also be used as appropriate for the specific FASOMGHG application. Shifts over time in non-wood production costs, recovery rates for solid wood products, Canadian delivered wood costs, all trade with countries or regions other than Canada, and non-Canadian softwood lumber import supply are derived in the same way.

Unlike some past intertemporal models in the forest sector (for example, Sedjo and Lyon, 1990; Sohngen et al, 1999), FASOMGHG does not assume an independent time-based improvement in timber yields. Following the approach of the 2000 RPA Timber Assessment (Haynes, 2003), aggregate yields can improve over time based on adoption of the more intensive, and higher yielding, timber management intensity classes on larger areas of the timberland base.

Thus, a unit of area allocated to a specific MIC in period t of the projection will promise the same yields at harvest as a unit allocated to the same MIC in any other period. Aggregate yields improve as more area is allocated to the more intensive regimes.

7.2.19 Valuing terminal standing inventory

The possibility of planting trees with a rotation length which would carry them beyond the explicit model time frame necessitates valuation of the standing inventory existing in the terminal projection period. At the time of planting, producers should anticipate a flow of costs and returns which justify stand establishment costs. The planting of a stand with an expected 30 year life in year 80 of a 100-year projection is potentially problematic, however, because the anticipated harvest date is beyond the model time frame. The mechanism reflecting the value of inventory involves specification of "terminal conditions" that represent the projected net present value for all time periods beyond the end of the model projection. Terminal conditions are resolved by computing the potential future even-flow of harvest from the terminal inventory and valuing this harvest using appropriate prices from downward sloping product demand curves and forested stands associated timber management and production costs.

Terminal period inventories are valued in both forest and agricultural sectors assuming perpetual, steady state management following the last year of the time horizon. In the forest sector, we used von Mantel's formula to estimate the perpetual yield of a fully regulated forest with volume equal to the model's terminal inventory at the end of the final period (see details in Chapter 14). The resultant yields were placed in time period 9999 and the full manufacturing, timber consumption and movement structure was also defined in that period. Demand relations for forestry in all periods beyond the end of the projection were taken to be the same as those in the final period. Thus terminal period prices, costs and revenues vary with level of output. Deducting costs, the resulting streams of net returns were treated as constant perpetual series.

7.2.20 GHG involvement

Management decisions involving the forestry sector have implications for net GHG emissions. We account for a number of the GHG implications are accounted for. Specifically the forest-related GHG accounts tracked are listed in table 7-12. These include GHG increments of six major types

- sequestration increments in forest soils
- sequestration increments in forest litter and understory or more generally the forest ecosystem not including trees and soils

- sequestration involved in standing trees
- sequestration in wood products
- biofuel offsets when wood products are burned
- carbon emissions when fossil fuels are used in forest production

These appear in the ***GHGACCOUNTS*** equation that is defined for each period wherein coefficients appear for the forest production and manufacturing variables (see the tableau in table 7-13 where the accounts are collapsed into one row). Specifically, carbon accounting is done in association with the ***FORPRDEXIST***, ***FORPRDNEW*** and ***FORPRDNEWAFFOREST*** forest production variables as well as with the ***FORWDMANUFACT*** wood product manufacturing variable. The accounting appearing underneath the forest production variables involves the sequestration in soils; litter and understory; and standing trees along with the emission accounting for forest production use of fossil fuels.

Forest production sequestration accounting is broken into 2 parts: one for continuing forests and one for first rotation forests established on lands coming over from agriculture. The reason for this is that the amount of carbon sequestered in forest soils can change dramatically between the beginning state of lands just transferring from agriculture and that observed on forest lands after progression to a mature forest

The accounting underneath the manufacturing variables involves the carbon sequestered in wood products and the fate of those products over time. This contains a number of accounts because the model explicitly portrays manufacturing activity in Canada and it is questionable whether it would be appropriate to include Canadian generated carbon offsets in US carbon accounting. It is anticipated that the Canadian carbon will not be counted in US payment schemes and as a consequence it is kept in a separate account to allow for its removal or unlikely addition.

Table 7-12. Forest related GHG accounts

Account Name	Brief description
Forest_ContinueSoil	Carbon in forest soil of forests that remain forests
Forest_AfforestSoil	Carbon in forest soil of afforested forests
Forest_ContinueLitUnd	Carbon in litter and understory of forests that remain forests
Forest_AfforestLitUnd	Carbon in litter and understory of afforested forests
Forest_ContinueTree	Carbon in trees of forests that remain forests
Forest_AfforestTree	Carbon in trees of afforested forests
Forest_USProduct	Carbon in US consumed and produced wood products
Forest_CANProduct	Carbon in US consumed but Canadian produced wood products

Forest_USExport	Carbon in US produced but exported wood products
Forest_USImport	Carbon in US consumed but imported from non Canadian source
Forest_USFuelWood	Carbon in US consumed fuelwood
Forest_USFuelResidue	Carbon in US residue that is burned
Carbon_For_Fuel	Carbon emissions from forest use of fossil fuel
Dev_ForestLand	Carbon on forest land after it moved into developed use

Table 7-13 Sample tableau illustrating forest related GHG model aspects

	Clearcut Exist Stand in T1	Clearcut Exist Stand in T1+k	Reforest Land in T1 then Clearcut in T1+k	Reforest Land in T1+k then Clearcut in T1+2k	Afforest Land in T1 then Clearcut in T1+k	Manufacture wood products in T1	Manufacture wood products in T1+k	Land from Ag in T1	Land to Ag in T1	Product demand	GHG payments	
Bare land in T_1	-1		1						1			= -dev1
Bare land from ag in T_1					1			-1				= 0
Exist Timberland	1	1										= L
Bare land in T_{1+k}		-1	-1	1	-1							= -dev1+k
Harvested Logs in T_1	$-he_1$					y						= 0
Harvested Logs in T_{1+k}		$-he_{1+k}$	$-hr_{1+k}$		$-ha_{1+k}$		y					= 0
Wood Products in T_1						-1				+		= 0
Wood Products in T_{1+k}							-1			+		= 0
GHG in T_1		cse_1	csn_1			cp_1					+	= -cdev1
GHG in T_2		cse_2	csn_2			cp_2					+	= -cdev2
GHG in T_{1+k}				csn_1	csa_1	cp_{1+k}	cp_1				+	= -cdev1+k
GHG in T_{1+2k}						cp_{1+2k}	cp_2				+	= -cdev1+2k

where

- T_n represents time period n and indexes the five year periods.
- k is the rotation age for new stands (note this is fixed only for display purposes)
- dev_n is the amount of land moving into developed uses in time period n
- L is the amount of land in existing stands at the model beginning
- he_n is the yield of logs from harvesting an existing stand in time period n
- hr_n is the yield of logs from harvesting an afforested stand in time period n.
- ha_n if the yield of logs from harvesting a reforested stand in time period n.
- y is the amount of logs needed to yield one unit of final wood product
- cse_n is the carbon sequestered less the net fossil fuel related emissions from an existing stand in the time period n
- csn_n is the carbon sequestered less the net fossil fuel related emissions from a reforested stand in the time period n
- csa_n is the carbon sequestered less the net fossil fuel related emissions from an afforested stand in the time period n
- cp_n is the amount of carbon sequestered in wood products n time periods after the wood product was manufactured.
- $cdev_n$ is the cumulative amount of carbon sequestered in all lands that moved from forestry into developed use in this and all previous periods

Several things can be observed from this tableau about the FASOMGHG conventions for GHG accounting:

- Forest production accounting is done from the period of forest establishment (or the first model period for preexisting stands) up until the last time period before the period of forest clearcut harvest. Accounting in the clearcut harvest period is picked up by the next production variable in the rotation and in the manufacturing variable. This is done because when land switches to agriculture its residual carbon characteristics would be quite different than if it were maintained in forestry. By doing our accounting in the next rotation variable we know where the land went. Thus continuing forest carbon accounting is done under the reforestation variable for forests and under the agricultural variables when land use changes.
- Carbon sequestered in wood products is accounted for underneath the forest manufacturing variable. The reason for this is that on manufacturing we know the country origin of the logs and can appropriately credit that carbon. We cannot do this underneath the consumption variables as, for example, 30% of US softwood lumber consumption is

of Canadian origin and one should likely not credit the carbon in that wood to US accounts.

- Carbon accounting differs for afforested and reforested stands. This is done simply to be able to track the rather large gain in soil carbon that is encountered during the first rotation.

Details on how all the carbon sequestration numbers are computed in the model are presented in the forest GHG related data section below.

7.2.21 Non-market management considerations

Inside FASOMGHG several model features are present to accommodate the fact that management of some forest land responds to an array of amenity and non-market forces. The first involves the notion of "limited management response" where some regions (those outside of the SC, SE, and PNWW) have limited management intensity choices. Second public lands harvest is totally exogenous. Third some timberlands can only be managed under a partial harvest regime. Fourth, we introduce a restriction that a given amount of forest land will always contain hardwoods. The ***FORHARDWOODMIN*** constraint imposes this limit, always requiring a minimum percentage of the forest lands to be in hardwoods in a region for each time period. Finally there is provision in the model for a limit on reforestation timber investment that can be used to restrict model solutions to mimic historical levels and patterns of regeneration investment spending. In earlier versions of FASOM, this constraint was used experimentally to limit investment by nonindustrial private forest land owners (Adams et al, 1998). This is implemented in the constraint ***FORSTICKY***.

7.3 Algebraic model

The general form of the forest sector model is illustrated in the following mathematical representation. Notation for some dimensions (such as time or product) has been dropped in some cases to simplify the exposition. Thus these relations should be viewed as representative of the general form of the model. We have also suppressed notation showing currency conversion via the exchange rate and any tariffs between the US and Canada. All monetary units are treated as US dollars.

7.3.1 Objective Function.

In the forestry portion of FASOMGHG the principal decision variables include the harvest and management of existing and newly regegerated or afforested timberland (X, N, AF), production of manufactured products (Y), levels of manufactured product demand (D), interregional transportation of logs and products (T), and aggregate shipments from producing regions (S). The forestry portion of the FASOMGHG objective function involves maximization of the discounted sum of producers' and consumers' surplus, less the costs of timber supplies from Canada that vary with volume harvested, less the costs of volume-sensitive non-wood inputs, transportation, manufacturing inputs, and forest management. In equation 7.___ total willingness to pay is computed under the product demand curves [Pik(.)]. An array of costs are then deducted: Canadian wood costs [C_{ik}(.)], the area under the marginal cost curves of those inputs whose costs vary with output [NWC_{ik}(.)], transportation costs [T_{jik}], non-wood costs for those inputs (labor, materials, energy in solidwood production) whose total does not vary with output [YC_{ikpx}], and the costs of forest management, such as planting and fertilization [MC].

Finally, because the projection is made for a finite time period (to year TMAX), we add an estimate of net surpluses in all periods beyond the end of the projection [TERM]. We assume that at the end of the final period the forest is fully regulated on a fixed rotation age (ROT measured in years). We compute the total volume of timber in the forest at that point, INV, and approximate the periodic sustained yield harvest volume (TERMCUT) using von Mantel's formula (see Davis and Johnson, 1987), where TERMCUT = 2 INV / (ROT / 5). The TERMCUT volume is then used to estimate production volumes and costs, surpluses in the demand relations, and ultimately a net surplus per future period [denoted TERM]. The discounted value at time TMAX of an infinite series of future payments occurring every ROT years is TERM/[$(1+r)^{ROT}$ - 1] which is then brought forward to the start of the projection.

$$
\begin{aligned}
&\underset{\{S,T,D,Y,X,N,AF\}}{\mathrm{MAX}} \sum_{t=1}^{TMAX} (\sum_k \int_0^D P_{ik}(D_k)dD_k - \sum_k \sum_i \int_0^S C_{ik}(S_{ik})dS_{ik} - \sum_k \sum_i \int_0^Y NWC_{ik}\left(\sum_x \sum_p Y_{ikpx}\right)dY_{ikpx} \\
&- \sum_k \sum_i \sum_j T_{jik} TC_{jik} - \sum_x \sum_p \sum_k \sum_i Y_{ikpx} YC_{ikpx} \\
&- \sum_i \sum_o \sum_m \{MC(i,o,t,m)[X(i,o,t,m) + N(i,o,a,t,m) + AF(i,o,a,t,m)]\}(1+r)^{-t} \\
&+ TERM(1+r)^{-TMAX} / [(1+r)^{ROT} - 1]
\end{aligned}
$$

NEED EQUATION NUMBERS -- -I'M NOT SURE HOW TO ADD THEM

7.3.2 Constraints

Constraints relate to manufacturing activities, treatment of the forest inventory, and land transfers to and from agriculture. Given their complexity, we do not show the GHG accounting relations.

7.3.2.1 Manufacturing capacity limitations.

Output can not exceed capacity. Capacities are defined at the process level within each product.

$$\sum_x Y_{ikpx} \leq K_{ikp}^o \quad \text{for region i, process p and product k}$$

7.3.2.2 Residue generation at processing facilities.

Residues are generated primarily at solid wood manufacturing facilities and may be transferred to other manufacturing processes, such a fiber products, burned to generate energy, or sent to land fills.

$$R_{ic} = \sum_x \sum_p \sum_k Y_{ikpx} G_{ikc} \quad \text{for region i and product c}$$

7.3.2.3 Supply of recycled paper products.

The fraction of a particular type of paper or paperboard recovered from the consumption stream is a fraction that may vary over time up to some maximum set by considerations of contamination of the stream, geographic dispersal, and mixing of the desired grade with other grades.

$$S_{ikt} = \sum_l \mu_{iklt} D_l \quad \text{for region i and product k}$$

7.3.2.4 Materials balance

In region i, the sum of shipments received plus harvests plus residues generated in manufacturing plus internal supplies (from products with explicit supply relations) plus production less demand (consumption) less use in manufacturing less shipment out of the region must be greater than zero. This is a general expression, listing all types of sources and uses. Not all of the terms are non-zero for every commodity.

$$\sum_j T_{jik} + \sum_o H_{iok} + R_{ik} + S_{ik} + \sum_x \sum_p Y_{ikpx} - D_{ik} - \sum_x \sum_p \sum_l Y_{ilpx} M_{iklpx} - \sum_j T_{ijk} \geq 0$$

for region i and product k

7.3.2.5 Harvest balances

The volume of harvest is defined as a function of the areas allocated to various management intensity classes, harvest times and associated yields. All stands are managed under some management intensity class (MIC) or silvicultural regime (denoted by the set m below), either even-aged without thinning (the subset m' of all regimes), even-aged with thinning, or partial cutting (both combined in the subset m^o of all regimes).

$$H_{iok} = \sum_m X(i,o,t,m)V(k,m) + \sum_m \sum_{a+v<t} N(i,o,a,t,m)V^N(k,t-a,m) +$$
$$\sum_{\tau>t} \sum_{m^0} [X(i,o,\tau,m^0)V_X^H(k,\tau,m^0) + N(i,o,a,\tau,m^o)V_N^H(k,\tau,m^0)]$$

for region i, owner o and product k.

Stands managed on an even-aged basis with thinning and stands managed on a partial cutting basis (MIC $\in$ m^o) produce harvest volumes at their preset thinning or partial cut times (i.e., times prior to their clearcut age if any, or $\tau > t$ in the notation below). Stands may be shifted between MICs during the projection. Land initially managed on an even-aged (clearcut) basis with no thinning can be harvested and replanted on a regime involving partial cutting (with an appropriate delay to the time of first partial cut). Stands initially enrolled in a partial cutting regime can be clearcut harvested, replanted and managed on an even-aged basis in subsequent periods. Thus the initial set of harvest yields in equation 7.___ involve summations over the full set of MICs (m) to cumulate the volume from all types of stands that might be clearcut in a given period. The second set of terms cumulate volumes from partial cuts or thinnings.

7.3.2.6 Management allocation of initial areas.

All timberland areas that exist at the start of the projection are allocated to some MIC based on inventory data and owner surveys. These areas must then be allocated to a harvest in some period. Note that existing stands allocated to a partial cutting regime can be clearcut (if it is optimal to do so) and replanted to some new even or partial cutting regime at some point in the future or they may remain in partial cutting for the entire projection (t = never). So stands can move back and forth between even and partial cutting regimes.

$$\sum_t X(i,o,t,m) = A(i,o,m) \text{ for region i, owner o and MIC m}$$

7.3.2.7 Reforestation of clearcut areas.

No more area can be reforested in period t than is clearcut harvested from existing, afforested or new stands in that period adjusted for any loss of land from agriculture and less any land that shifts to developed uses. Again, stands in partial cutting regimes can be clearcut at some point in the projection and regenerated to either an even or partial cutting regime. Land transferred from agriculture must be afforested in the period transferred and these areas are considered in a separate constraint (see constraint h).

$$\begin{aligned}\sum_{m'}\sum_{l>t+v} \mathrm{N(i,o,t,l,m')} \le \sum_{m} \mathrm{X(i,o,t,m')} + \sum_{a+v<t} \mathrm{AF(i,o,a,t,m')} \\ + \sum_{m'}\sum_{a+v<t} \mathrm{N(i,o,a,t,m')} - \mathrm{LTA(i,o,t)} - \mathrm{DL(i,o,t)}\end{aligned} \quad \text{for region i, owner o, period t}$$

7.3.2.8 Afforestation.

Land that moves to forestry from agriculture must be planted in the period it shifts uses. It may be allocated to even and partial cutting regimes.

$$\sum_m AF(i,o,t,m) = LFA(i,o,t) \text{ for region i, owner o and period t}$$

7.3.3 Symbol definition

Sets

i,j sets of forest regions

k,l,c sets of wood product commodities

m = [m^o,m'] the set of possible management intensity class assignments, where m^o comprises even-aged thinning or partial cutting options and m' options involving only clearcutting. Areas allocated to partial cutting may be clearcut in a period when no partial cut is scheduled. They then enter the regeneration pool and may be replanted to a partial cutting or any other regime.

o set of forest owners

p set of wood product production processes

x set of wood product manufacturing input mixes

Coefficients (Parameters)

μ_{iklt} fraction of recycled paper product k recovered in region i, period t from paper products l (in some cases several types of paper products can contribute to a given class of recycled paper)

G_{ikc} generation of residue commodity *c* during manufacture a unit of commodity *k* in region *i*.

K_{ikp} manufacturing capacity for process *p*, commodity *k* in region *i*.

M_{iklpx} consumption of commodity *l* to manufacture a unit of commodity *k* utilizing production process *p* and input mix *x* in region *i*.

TC_{jix} cost of transporting a unit of commodity *k* from region *j* to region *i*.

YC_{ikpx} cost of manufacturing a unit of commodity *k* utilizing production process *p* and input mix *x* in region *i*.

Variables and functions

A(i,o,m) initial (exogenous) area in region i, ownership o, and MIC m

AF(i,o,a,t) land that is afforested in period a and scheduled to be harvested i period t > a in region i, owner o

$C_{ik}(S_{ik})$ cost-dependent supply function for commodity k in region i

D_{ik} demand variable for commodity *k* region *i*.

DL(i,o,t) forest land lost to developed uses in region i, owner o, period t

H(i,o,k,t) harvest volume for log commodity *k* by owner *o* in region *i*, period t.

LFA(i,o,t) land transferred from agriculture to forestry in region i, owner o, period t

LTA(i,o,t) land transferred from forestry to agriculture in region i, owner o, period t

MC(i,o,t,m) forest management costs per unit are for land in region i, owner o, under MIC m

N(i,o,a,t,m) forest land planted in period a and harvested again in period t, in region i owner o in MIC m—termed "new" areas since they are created after the start of the projection. A stand regenerated to a partial cutting (or thinning) regime will be subject to the partial harvests (r thinnings) until period t when it is clearcut and regenerated. A partial cut stand may be scheduled for harvest in t = never, so retained in the partial cut regime until the end of the projection.

$NWC_{ik}\left(\sum_x \sum_p Y_{ikpx}\right)$ non-wood input function for commodity *k* region *i*. Non-wood inputs for commodity k depend on the quantity of k produced.

$P_k(D_k)$ price-dependent demand function for commodity k

R_{ik} residue generation per unit of commodity *k,* region *i*

ROT rotation age on which forests are assumed to be managed in periods after the end of the projection (t > TMAX)

S_{ikt} supply of commodity *k* region *i*

T_{jik} transport of commodity *k* from region *j* to region *i*

TERM periodic net surplus in periods after TMAX

TMAX length of projection period

$V(k,m')$, $V^N(k,t\text{-}a,m')$, $V_X{}^H(k,t,m^o)$, $V_N{}^H(k,t,m^o)$ are volumes of product k per acre on timberland managed in even-aged MICs in the initial stands (*V*), under even-aged MICs in new stands (V^N), and under partial cutting and thinning in new and existing stands ($V_X{}^H$, $V_N{}^H$).

X(i,o,t,m) forest land in region i, owner o that existed at the start of the projection that is allocated to some MIC (m) and is scheduled to be cut in period t. Stands in partial cutting regimes may be retained in those regimes for the entire projection (t = never) or clearcut and regenerated to any other feasible regime.

Y_{ikpx} manufacture of commodity *k* utilizing production process *p* and input mix *x* in region *i*.

8 CHAPTER 8 AG SECTOR MODELING DETAILS

FASOMGHG contains an adaptation of the ASM model (Chang et al) and the ASMGHG variant (Schneider, McCarl and Schneider) as a submodel. This model is wholely included as a submodel in FASOMGHG appearing in each explicit time period. This agricultural sector submodel depicts crop and livestock production and agricultural processing using key land, water, labor, and forage inputs as well as product trade.

The agricultural sector submodel simulates the effects of changes in agricultural resources and market conditions on prices, quantities produced, consumers' and producers' surplus, exports, imports, and processing. The submodel considers production, processing, domestic consumption, imports, exports, and input procurement. The submodel distinguishes between primary and secondary commodities, with primary commodities being those directly produced by farms and secondary commodities being those involving processing.

For agricultural production the US is disaggregated into either 63 or 11 geographical subregions depending on time period. Each subregion possesses different endowments of land, labor, irrigation water and AUM grazing, as well as crop and livestock yields. The supply sector allocates these regional factors across a set of regional crop and livestock budgets and a set of processing budgets which use commodities as inputs. There are more than 1200 production possibilities (budgets) representing agricultural production in each time period. These include field crop, livestock, and biofuel feedstock production. The field crop variables are also divided into irrigated and dryland production according to the irrigation water and production possibilities available in each region. There are also import supply functions from the rest of the world for a number of commodities. The demand sector of the model is constituted by the intermediate use of all the primary and secondary commodities, domestic consumption, and exports.

Secondary commodities are produced by processing variables. They include soybean crushing, corn wet-milling, potato processing, sweetener manufacturing, mixing of various livestock and poultry feeds, and the conversion of livestock and milk into consumable meat and dairy products. The processing cost is generally calculated as the difference between its price and the costs of the primary commodity inputs.

Primary and secondary commodities are consumed at the national level according to constant elasticity demand functions. The areas under these demand functions represent total willingness to pay for agricultural products. The difference between total willingness to pay and production and processing costs is equal to the sum of producers' and consumers' surpluses. Maximization of the sum of these surpluses constitutes the agricultural sector objective function.

The basic relations in the agricultural sector model are treated as if they represent typical repeating activity in each year of each time period. Demand and supply components are updated between time periods by means of projected growth rates in yield, processing efficiency, domestic demand, exports, and imports.

The agricultural related land use decision simulated in FASOMGHG is that, in each period, owners of agricultural land can decide: 1) whether to keep an acre of land in agricultural production or change land use to afforestation; 2) what crop/liversock mix to plant/rear/harvest, if the land stays in agriculture; and 3) what type of timber management to select, if the land is to be planted in trees. These decisions are made entirely on the basis of relative profitability of land in its various competing alternative uses over the life-span of the foreseeable choices (for land in either crops or trees).

Here we

- discuss the basic scope of the agricultural sector representation
- present an overview tableau
- delve into model details showing key features

8.1 Scope of agricultural sector representation

8.1.1 Regional Disaggregation

The model operates with two levels of regional disaggregation. The fundamental unit of disaggregation is 63 state and/or substate subregions. These smaller subregions uniquely fall into one of the 11 FASOMGHG larger regions. A listing of the aggregate and more disaggregated regions are given in Tables 3-1 and 3-2 respectively.

8.1.2 Characterizing the landscape and the sector

8.1.2.1 Land

Agricultural land is defined into two fundamental types: crop and pasture land. Four crop land quality classes are defined as follows. First, all crop land with USDA Land Capability Class III to VIII having a subclass of "w", i.e., a wetness limitation for cropping, was grouped and labeled

w3-8 wet lands.

The remaining crop land was divided into three groups according to its erodibility index (ei). The ei is either RKLS/T from the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) or WEQ/T from the Wind Erosion Equation, depending on whether wind or water erosion gives the larger ei ("T", the soil loss tolerance level, is the maximum allowable erosion for sustained crop production. The three ei groups are:

Loei land has ei < 8.0;
Mdei land has 8.0 <= ei < 20.0
Svei land has ei >= 20.0 in "svei".

8.1.2.2 Crops

A set of crops is modeled that depicts the majority of agricultural land use. These are listed in Table 3-9 and include

Food grains: wheat (4 types) and rice
Feed grains: corn, oats, barley, sorghum
Cotton
Soybeans
Sugar crops: beets and cane
Potatoes
Citrus: oranges and grapefruit
Tomatoes
Hay
Silage
Biofuel feed stocks: switch grass, hybrid poplar and willow.

8.1.2.3 Animals

A set of animal types are modeled that collectively represent the majority of the resources used by livestock. These are listed in Table 3-10 and includes

Sheep
Beef cattle at the cow calf, stocker and feedlot stages
Dairy cattle
Hogs at the feeder pig, farrow to finish and finishing stages
Poultry
  Turkeys
  Broilers
  Egg layers
Horses and mules

8.1.3 Commodities

8.1.3.1 Primary Commodities

There are 56 primary agricultural commodities AS listed in Table 3-6. The primary commodities depict the majority of total agricultural production, land use and economic value. They can be grouped into crops, livestock and biofuels related commodities.

The crop commodities are

Food grains: wheat (durham, soft red winter, hard red winter hard red spring) and rice
Feed grains: corn, oats, barley, sorghum
Cotton
Soybeans
Sugar crops: beets and cane
Potatoes (fresh and processed)
Citrus: oranges and grapefruit (fresh and processed by box size)
Tomatoes (fresh and processed)
Hay
Silage
Biofuel feed stocks: switch grass, hybrid poplar and willow.

The livestock commodities by animal grouping are

Sheep (lambs for slaughter, cull ewes, wool)
Beef cattle
  Cow calf (calves for slaughter, cull beef cows, steer calves, heifer calves)

Stocker (nonfed slaughter, stocked calves, stocked heifer calves, stocked steer calves, stocked yearling, stocked heifer yearling, stocked steer yearling)
Feedlot (fed beef slaughter)
Dairy cattle (milk, cull dairy cows, dairy calves)
Hogs
Feederpig (cull sows, feeder pigs)
Farrow to finish (cull sows, hogs for slaughter)
Finishing stages (hogs for slaughter)
Poultry
Turkeys (turkey for slaughter)
Broilers (chicken for slaughter)
Eggs
Horses and mules

8.1.3.2 Secondary commodities

The FASOMGHG agricultural submodel incorporates processing of primary commodities into secondary commodities. Table 3-7 lists the 39 secondary commodities that are created by processing. These commodities are chosen based on their linkages to agriculture. Some primary commodities are inputs to processing activities yielding these secondary commodities. Certain secondary products (by-products) are in turn inputs to agricultural livestock production or feed blending. These can be broken into crop, livestock and biofuels related items. The crop related secondary items by major class are:

Processed citrus products -- orange juice, grapefruit juice
Crushed soybean products -- soybean meal, soybean oil
Corn wet milling products -- high fructose corn syrup, gluten feed, corn starch, corn oil, corn syrup, dextrose
Sweetened products -- beverages, confection, baking, canning
Refined sugar items-- refined sugar, refined cane
Potato products -- frozen potatoes, dried potatoes, potato chips

The livestock related items by major class are:

Meat items
Beef -- fed beef, non fed beef
Pork
Chicken
Turkey
Clean wool

Dairy products -- fluid milk, cream, skim milk, evaporated condensed milk, non fat dry milk, butter, american cheese, other cheese, cottage cheese, ice cream

The biofuels related items are:

Ethanol
Blended gasoline that contains ethanol (subsidized and unsubsidized)
Biodiesel
Electricity generated with biofuels feedstocks in terms of BTU content of feedstock

8.1.3.3 Blended feeds

The agricultural submodel incorporates mixing of feeds for livestock consumption. Table 3-8 lists the 20 blended feed categories. Grouped by major animal type these are

- Beef
  - Cow calf -- cow calf grain, cow calf protein supplement
  - Stockers -- stocker protein supplement
  - Feedlot -- cattle grain, high protein cattle feed
- Hogs
  - Feeder pig -- farrowing grain, farrowing protein feed, feeder pig grain, feeder pig protein
  - Farrow-finish— farrowing grain, farrowing protein feed, feeder pig grain, feeder pig protein, finishing grain, finishing protein feed
  - Finishing -- finishing grain, finishing protein feed
- Dairy -- Dairy concentrate
- Poultry
  - Broilers -- broiler grain, broiler protein feed
  - Turkeys-- turkey grain, turkey protein feed
  - Egg layers-- egg layer grain, egg layer protein feed
- Sheep -- sheep grain, sheep protein feed

8.1.4 Non land inputs

In the model there is modeling of water, labor, animal unit month grazing, national inputs and blended feed inputs.

8.1.4.1 Water

The water supply is divided into fixed price supply (generally public surface waater) and pumped upward sloping supply (generally ground or private surface water) components. The fixed price water is available for a constant price up to a maximum quatity. The pumped upward sloping water is provided according to a supply schedule where increasing amounts of water are available for higher prices.

8.1.4.2 Labor

The labor input includes two components: family labor and hired labor. The family labor is available at a fixed reservation wage up to a maximum amount. The hired labor is based on an inducement wage rate which is higher than the reservation wage and a supply function from thereon.

8.1.4.3 Grazing in AUMS

Grazing land supply is provided on an animal unit month (AUM) basis. Its supply is divided into public and private sources. Public grazing is available at a constant price (a grazing fee) up to a maximum availability. Private grazing is supplied according to an upward-sloping supply schedule.

8.1.4.4 National Inputs

The model represets use of 168 national inputs. They are listed in the file ***data_aginputname.gms.*** These are specified in dollar terms so they are homogeneous within each calss; for example, ten dollars worth of nitrogen, twenty dollars worth of repair cost. They include things like fertilizer expenditures by fertilizer type, pesticide expenditures use by type, chemical expenditures, energy expenditures, equipment expenditures, custom operator expenditures, feed additive expenditures, capital expenditures, interest costs, and animal health expenditures among many other items.

8.1.4.5 Blended and other feed

Crops are not only outputs but are also inputs for direct use by livestock or in feed blending processes. In addition the blended feeds as listed above are intermediate inputs to livestock production. Some of the secondary commodities like gluten feed and soybean meal are also directly used as inputs to livestock production and are used in feed blending procedures.

8.1.5 Agricultural Production

Crops and livestock can be produced.

8.1.5.1 Crops

The crop production set is defined at the 63 region level and currently includes more than 1200 production possibilities (budgets). Yields, costs and input usare rates vary by region. These include major field crop production, livestock production, and biofuel feedstock production. In addition they are defined across multiple land types (the four defined above), irrigation possibilities (irrigated and dryland), fertilization alternatives (3 alternatives -- base fertilization then 15% and 30% reductions from the base) and tillage alternatives (3 alternatives -- conventional, minimum and no till). Yield, water use, and erosion data for these alternatives are defined based on runs of the EPIC crop growth simulator.

8.1.5.2 Livestock

Livestock production alternatives are defined for the 63 regions for the animal types defined above. In addition some alternative production possibilities are defined that alter feed and land inputs.

8.1.6 Agricultural Processing

The processing activities generally reflect a simplified processing representation concentrating on the commodities used. They largely depict primary/secondary commodity usage, secondary commodity yield and a level of cost. Thus, for example, the soybean crushing processing activity uses one unit of soybeans and generates a given number of pounds of soybean meal and tons of soybean oil at a cost. The cost is usually the observed price differential between the value of the outputs and the value of the raw commodities used where both are valued at observed prices.

Processing activities are defined partially at a regional level and partially at a national level largely depending on market conditions for the crop and livestock primary commodities. The regional activities are listed below in Tale 8-1 followed by a list of the national commodities (Table 8-2).

Table 8-1 Processing activities that are defined on a regional basis

Regional activity code	**Brief description**
SoyCrush1	Crush soybeans
WetMill	Wet mill corn

Gluttosbm	Substitute gluten feed for soybean meal
SwitchgrassToElec	Make switchgrass into electricity
HybridpoplarToElec	Make hybrid poplar into electricity
WillowToElec	Make willow into electricity
SwitchgrassToEthanol	Make switchgrass into ethanol
HybridpoplarToEthanol	Make hybrid poplar into ethanol
WillowToEthanol	Make willow into ethanol
MakeBiodiesel	Make biodiesel

Table 8-2 Processing activities that are defined on a national basis

National activity code	**Brief description**
makeAmCheese	Make American cheese
makeOtCheese	Make other cheese
ButterPow	Make butter and non fat dry milk powder
FluidMlk1	Make two percent milk
FluidMlk2	Make skim milk
EvapoMilk	Make evaporated milk
IceCream1	Make ice cream alternative 1
IceCream2	Make ice cream alternative 2
Cottage	Make cottage cheese
makeHFCS	Make high fructose corn syrup
makeCSyrup	Make corn syrup
makeBeverages	Make sweetened beverages
makeConfection	Make sweetened confectionaries
makeBaking	Make sweetened baked goods
makeCanning	Make sweetened canned goods
makeEthanol	Make ethanol from corn
makeMktGasBlend	Make unsubsidized liquid fuel blending gasoline & ethanol
makeSubGasBlend	Make subsidized liquid fuel blending gasoline & ethanol
makeDextrose	Make dextrose
CleanWool	Convert wool to clean wool
RefSugar1	Convert sugar cane to raw cane sugar
RefSugar2	Convert sugar beets to refined sugar
CaneRefine	Convert raw cane sugar to refined sugar
HogToPork	Convert finished hogs to pork
BroilChick	Convert broilers to chicken meat
TurkeyProc	Convert live turkeys to turkey meat
SowToPork	Convert cull sow to pork
ClCowSla	Convert cull cow to non fed slaughter
DCowSla	Convert cull dairy cow to non fed slaughter
NFSlatonF	Convert non fed animal to non fed slaughter
FSlatofBe	Convert fed animal to fed slaughter

DClfToBeef	Convert cull dairy calf to non fed slaughter
StockSteerCalftoFeed	Move stocked steer calf into feedlot
StockHeiferCalftoFeed	Move stocked heifer calf into feedlot
StockSteerYearlingtoFeed	Move stocked steer yearling into feedlot
StockHeiferYearlingtoFeed	Move stocked heifer yearling into feedlot
HeiferYearlingSlaughter	Slaughter a heifer yearling
SteerYearlingSlaughter	Slaughter a steer yearling
Frozen-Pot	Make frozen potatoes
DeHydr-Pot	Make dehydrated potatoes
CHIP-POT	Make potato chips
JuiceOrang	Make orange juice
JuiceGrpft	Make grapefruit juice

8.1.7 Feed blending

FASOMGHG depicts the blending of 20 different types of feeds that, in turn, are used within the livestock production alternatives. For each feed, a number of blending alternatives are specified. The feed alternatives, their names and a list of the alternative blending formula names are given in table 8-3. The alternative names are only presented to depict how much diversity is allowed for the blend of any one feed.

The optimal feed composition is a convex combination of the blending alternatives. These alternatives are regionally specific allowing the optimal feed blend to adapt to the relative regional abundance and price of the commodities used in the feed blend. The data specifying the feed alternatives are regionally adapted. For example, blending alternatives in regions where sorghum is produced reflect substitution possibilities of sorghum for corn. Table 8-3 lists the codes for the feeds, provides brief description and the blending alternatives defined.

Table 8-3 Feed blended and alternatives that make them

Feed Code	Feed description	Blending alternatives
StockPro0	Protein feed for stockers	stkpromix0, stkpromix2
CatGrain0	Blend of grains for finishing cattle	beefbases, beefalt1s, beefalt2s, beefalt3s, beefalt4s, beefalt5s,beefalt6s, beefalt7s, beefbasew, beefalt1w, beefalt2w, beefalt3w,beefalt4w, beefalt5w, beefalt6w, beefalt7w, beefbaset, beefalt4t, beefalt5t, beefalt6t, beefalt7t, beefbased, beefalt1d, beefalt2d, beefalt3d, beefalt4d, beefalt5d, beefalt6d, beefalt7d
HighProtCa	Protein feed for finishing cattle	catpro1, catpro3
CowGrain0	Blend of grains for cow calf operations	cowbases, cowalt1s, cowalt2s, cowalt3s, cowalt4s, cowalt5s, cowalt6s, cowalt7s, cowbasew, cowalt1w, cowalt2w, cowalt3w, cowalt4w, cowalt5w, cowalt6w, cowalt7w, cowbaset, cowalt4t, cowalt5t, cowalt6t, cowalt7t, cowbased, cowalt1d, cowalt2d, cowalt3d, cowalt4d, cowalt5d, cowalt6d, cowalt7d
CowHiPro0	Protein feed for cow calf operations	Cowpromix0, cowpromix2
FinGrain0	Blend of grains for pig finishing	basemix1s, alt1mix1s, alt2mix1s, alt3mix1s, alt4mix1s, alt5mix1s, alt6mix1s, alt7mix1s, basemix1w, alt1mix1w, alt2mix1w, alt3mix1w, alt4mix1w, alt5mix1w, alt6mix1w, alt7mix1w, basemix1t, alt1mix1t, alt2mix1t, alt3mix1t, alt4mix1t, alt5mix1t, alt6mix1t, alt7mix1t, basemix1d, alt1mix1d, alt2mix1d, alt3mix1d, alt4mix1d, alt5mix1d, alt6mix1d, alt7mix1d
FinProSwn0	Protein feed for pig finishing	finpromix0, finpromix6
FarGrain0	Blend of grains for farrowing operations	hogbases, hogalt1s, hogalt2s, hogalt3s, hogalt4s, hogalt5s, hogalt6s, hogalt7s, hogbasew, hogalt1w, hogalt2w, hogalt3w, hogalt4w, hogalt5w, hogalt6w, hogalt7w, hogbaset, hogalt1t, hogalt2t, hogalt3t, hogalt4t, hogalt5t, hogalt6t, hogalt7t, hogbased, hogalt1d, hogalt2d, hogalt3d, hogalt4d, hogalt5d, hogalt6d, hogalt7d
FarProSwn0	Protein feed for farrowing operations	farpromix0, farpromix6
FPGGrain0	Blend of grains for feeder pigs	basemix2s, alt1mix2s, alt2mix2s, alt3mix2s, alt4mix2s, alt5mix2s, alt6mix2s, alt7mix2s, basemix2w, alt1mix2w, alt2mix2w, alt3mix2w, alt4mix2w, alt5mix2w, alt6mix2w, alt7mix2w, basemix2t, alt1mix2t, alt2mix2t, alt3mix2t, alt4mix2t, alt5mix2t, alt6mix2t, alt7mix2t, basemix2d, alt1mix2d, alt2mix2d, alt3mix2d, alt4mix2d, alt5mix2d, alt6mix2d, alt7mix2d
FPGProSwn0	Protein feed for feeder pigs	fdppromix0, fdppromix6
DairyCon0	Blend of grains for dairy operations	dairybases, dairyalt1s, dairyalt2s, dairyalt3s, dairyalt4s, dairyalt5s, dairyalt6s, dairyalt7s, dairybasew, dairyalt1w, dairyalt2w, dairyalt3w, dairyalt4w, dairyalt5w, dairyalt6w, dairyalt7w, dairybaset, dairyalt1t, dairyalt2t, dairyalt3t, dairyalt4t, dairyalt5t, dairyalt6t, dairyalt7t, dairybased, dairyalt1d, dairyalt2d, dairyalt3d, dairyalt4d, dairyalt5d, dairyalt6d, dairyalt7d
BroilGrn0	Blend of grains for broilers	brobases, broalt1s, broalt2s, broalt3s, broalt4s, broalt5s, broalt6s, broalt7s, brobasew, broalt1w, broalt2w, broalt3w, broalt4w, broalt5w, broalt6w, broalt7w, brobaset, broalt4t, broalt5t, brobased, broalt1d, broalt2d, broalt3d, broalt4d, broalt5d, broalt6d, broalt7d
BroilPro0	Protein feed for broilers	brlpromix0, brlpromix4
TurkeyGrn0	Blend of grains for turkeys	polbases, polalt1s, polalt2s, polalt3s, polalt4s, polalt5s, polalt6s, polalt7s, polbasew, polalt1w, polalt2w, polalt3w, polalt4w, polalt5w, polalt6w, polalt7w, polbaset, polalt4t, polalt5t, polbased, polalt1d, polalt2d, polalt3d, polalt4d, polalt5d, polalt6d, polalt7d
TurkeyPro0	Protein feed for turkeys	trkpromix0, trkpromix4
EggGrain0	Blend of grains for eggs	eggbases, eggalt1s, eggalt2s, eggalt3s, eggalt4s, eggalt5s, eggalt6s, eggalt7s, eggbasew, eggalt1w, eggalt2w, eggalt3w, eggalt4w, eggalt5w, eggalt6w, eggalt7w, eggbaset, eggalt4t, eggalt5t, eggbased, eggalt1d, eggalt2d, eggalt3d, eggalt4d, eggalt5d, eggalt6d, eggalt7d
EggPro0	Protein feed for eggs	eggpromix0, eggpromix5
SheepGrn0	Blend of grains for sheep	bases, alt1s, alt2s, alt3s, alt4s, alt5s, alt6s, alt7s, basew, alt1w, alt2w, alt3w, alt4w, alt5w, alt6w, alt7w, baset, alt1t, alt2t, alt3t, alt4t, alt5t, alt6t, alt7t, based, alt1d, alt2d, alt3d, alt4d, alt5d, alt6d, alt7d
SheepPro0	Protein feed for sheep	shppromix0, shppromix2

8.1.8 Commodity Markets

The commodity market representation generally contains multiple possibilities for consumption and supply of a commodity. The consumption possibilities include domestic consumption, and exports along with intermediate product use. The intermediate product use possibilities include direct consumption by livestock (i.e. silage use in a dairy), use in livestock feed blends (i.e. corn in a hog finishing grain blend), or use as an input to processing (i.e. soybeans as an input to a soybean crushing operation). The supply possibilities include domestic production (i.e. corn from farm production), yields from processing (i.e. distillers grain from wet milling), yields from feed blending (i.e. blended hog finishing grain mix), and imports.

Markets are either regionalized or national. The regionalized markets are present for only a subset of the commodities while all commodities are subject to a national market at least for domestic consumption. The primary commodities with regional markets are listed in table 8-4 while the secondary commodities with such markets are listed in table 8-5 and blended feeds in table 8-6.

Table 8-4 Primary commodities with regional markets

FASOMGHG Code	Brief Description
Corn	Corn in bushels
Soybeans	Soybeans in bushels
SoftWhiteWheat	Soft White wheat in bushels
HardRedWinterWheat	Hard Red Winter Wheat in bushels
DurhamWheat	Durham Wheat in bushels
HardRedSpringWheat	Hard Red Spring Wheat in bushels
Sorghum	Sorghum in cwt
Rice	Rice in cwt
Silage	Silage in US tons
Hay	Hay in US tons
SwitchGrass	Switch grass in US tons
HybrdPoplar	Hybrid poplar in US tons
Willow	Willow in US tons

Table 8-5 Secondary commodities with regional markets

FASMGHG Code	Brief Description
SoybeanMeal	Soybean Meal in US tons
GlutenFeed	Gluten Feed in 100 lbs

Table 8-6 Blended feed commodities with regional markets

FASMGHG Code	Brief Description
StockPro0	Protein feed for stockers in 100 lbs (cwt)
CatGrain0	Blend of grains for cattle in 100 lbs (cwt)
HighProtCa	Protein feed for cattle in 100 lbs (cwt)
CowGrain0	Blend of grains for cow calf operations in 100 lbs (cwt)
CowHiPro0	Protein feed for cow calf operations in 100 lbs (cwt)
FinGrain0	Blend of grains for pig finishing in 100 lbs (cwt)
FinProSwn0	Protein feed for pig finishing in 100 lbs (cwt)
FarGrain0	Blend of grains for farrowing operations in 100 lbs (cwt)
FarProSwn0	Protein feed for farrowing operations in 100 lbs (cwt)
FPGGrain0	Blend of grains for feeder pigs in 100 lbs (cwt)
FPGProSwn0	Protein feed for feeder pigs in 100 lbs (cwt)
DairyCon0	Blend of grains for dairy operations in 100 lbs (cwt)
BroilGrn0	Blend of grains for broilers in 100 lbs (cwt)
BroilPro0	Protein feed for broilers in 100 lbs (cwt)
TurkeyGrn0	Blend of grains for turkeys in 100 lbs (cwt)
TurkeyPro0	Protein feed for turkeys in 100 lbs (cwt)
EggGrain0	Blend of grains for eggs in 100 lbs (cwt)
EggPro0	Protein feed for eggs in 100 lbs (cwt)
SheepGrn0	Blend of grains for sheep in 100 lbs (cwt)
SheepPro0	Protein feed for sheep in 100 lbs (cwt)

When both regional and national markets are defined for a commodity FASOMGHG reflects a movement from the regional market to the national market at the cost of the historically observed region to nation price differential. When a commodity has a regional market then domestic transport becomes a source of consumption where goods can be moved outside the region and a source of supply when goods are moved into a region.

8.1.9 International Trade

Three types of agricultural commodity trade arrangements are represented. Agricultural primary and secondary commodities may be portrayed

- With trade occurring in explicit international markets using a Takayama and Judge style, spatial equilibrium submodel that portrays country/regional level excess demand on behalf of a set of foreign countries/regions, excess supply on behalf of a set of foreign countries/regions and interregional trade between the foreign regions themselves and with the US.
- With the US facing a single excess supply and or excess demand relationship on behalf of the rest of the world or
- Without being subject to international trade.

8.1.9.1 Spatially traded commodities

When commodities are subject to explicit spatial interregional trade with spatial equilibrium submodels, then trading is portrayed with the 27 countries/foreign regions listed in table 3-7. In those countries/foreign regions, there are explicit supply and demand functions. Table 8-7 gives the commodities that are traded and the countries/regions which supply and demand them in the model. Note when a country supplies it can either export to another explicit country or to the US. Similarly, demand in a country/region can be met from either imports from other countries or from the US.

Table 8-7 Commodities that are traded and the countries/regions involved

FASOMGHG Code	Exporting countries	Importing countries
Corn	Others, S-Africa, China, Argentina	SW-Euro, E-Europe, E-Medit, N-Africa, E-Africa, Pers-GF, SE-Asia, Taiwan, S-Korea, Japan, Adriatic, Caribbean, E-Mexico, ES-America, WS-America, Indonesia, KoreaRep, Thailand, Canada
Soybeans	Argentina, Brazil	NC-Euro, E-Europe, USSR, N-Africa, SE-Asia, Taiwan, S-Korea, Japan, China, E-Mexico
SoftWhiteWheat	Australia, EEC, Canada	SW-Euro, USSR, E-Medit, N-Africa, W-Africa, S-Africa, Red-Sea, Pers-GF, SE-Asia, W-Asia, Taiwan, S-Korea, Japan, China, E-Mexico, ES-America, WS-America, Brazil, Bangladesh, Indonesia, KoreaRep, Pakistan, Philippine, Thailand, Vietnam
HardRedWinterWheat	Argentina, Australia, Canada	SW-Euro, USSR, E-Medit, N-Africa, W-Africa, S-Africa, Red-Sea, Pers-GF, SE-Asia, W-Asia, Taiwan, S-Korea, Japan, China, E-Mexico, ES-America, WS-America, Brazil, Bangladesh, Indonesia, KoreaRep, Pakistan, Philippine, Thailand, Vietnam
DurhamWheat	EEC, Canada	SW-Euro, USSR, N-Africa, S-Africa, SE-Asia, Taiwan, S-Korea, Japan, ES-America, WS-America, Brazil, Bangladesh, Indonesia, KoreaRep, Pakistan, Philippine, Thailand, Vietnam
HardRedSpringWheat	Australia, Canada	SW-Euro, USSR, E-Medit, N-Africa, W-Africa, S-Africa, Red-Sea, Pers-GF, SE-Asia, W-Asia, Taiwan, S-Korea, Japan, China, ES-America, WS-America, Brazil, Bangladesh, Indonesia, KoreaRep, Pakistan, Philippine, Thailand, Vietnam
Sorghum	Others, Red-Sea, China, Argentina, Australia	NC-Euro, E-Medit, Taiwan, S-Korea, Japan, E-Mexico
Rice	Others, China, ES-America, Argentina, Australia, India, Myanmar, Pakistan, Thailand, Vietnam	Others, SW-Euro, E-Europe, USSR, E-Medit, W-Africa, S-Africa, Red-Sea, Pers-GF, SE-Asia, W-Asia, S-Korea, Japan, Adriatic, Caribbean, E-Mexico, WS-America, Brazil, Bangladesh, Indonesia, KoreaRep, Philippine, Canada

8.1.9.2 Excess supply/demand commodities

When US trade is subject to just excess import supply and export demand functions, then the curves represent the level of total rest of world exports and imports that are faced at the national US market level. The commodities treated by this arrangement are listed in table 8-8.

Table 8-8 Commodities with rest of world export or import possibilities

FASOMGHG Code	Imported into the US	Exported from the US
Cotton	-	X
Oats	X	X
Barley	-	X
Sugarcane	X	X
Potatoes	X	X
TomatoFrsh	X	X
TomatoProc	X	X
OrangeFrsh75box	X	X
GrpfrtFrsh85box	X	X
Eggs	X	X
OrangeJuic	X	X
GrpfrtJuic	X	X
SoybeanMeal	-	X
SoybeanOil	-	X
HFCS	-	X
Confection	X	
GlutenFeed	-	X
FrozenPot	X	X
DriedPot	X	X
ChipPot	-	X
CaneRefini	X	
FedBeef	-	X
NonFedBeef	X	
Pork	X	X
Chicken	-	X
Turkey	-	X
WoolClean	X	X
EvapCondM	X	X
NonFatDryM	X	X
Butter	X	X
AmCheese	X	X
OtCheese	X	X

8.1.9.3 Commodities without trade

Commodities without explicit trade are generally specified as such because either the trade numbers are small or the commodity is not traded. These include the commodities listed in the table 8-9 below and all of the blended feeds.

Table 8-9 Commodities without international trade possibilities

FASOMGHG Code
Silage
Hay
Sugarbeet
OrangeFrsh90box
OrangeFrsh85box
OrangeProc75box
OrangeProc90box
OrangeProc85box
GrpfrtFrsh67box
GrpfrtFrsh80box
GrpfrtProc67box
GrpfrtProc85box
GrpfrtProc80box
SwitchGrass
HybrdPoplar
Willow
NonFedSla
FeedlotBeefSlaughter
CalfSlaugh
CullBeefCo
Milk
CullDairyCows
HogsforSlaughter
FeederPig
CullSow
LambSlaugh
CullEwes
Wool
SteerCalve
HeifCalve
StockedCalf
StockedHCalf
StockedSCalf

DairyCalves
StockedYearling
StockedHYearl
StockedSYearl
HorsesandMules
Broilers
Turkeys
Beverages
Baking
Canning
RefSugar
CornStarch
CornOil
CornSyrup
Dextrose
FluidMilk
Cream
SkimMilk
CottageChe
IceCream
Ethanol
MktGasBlend
SubGasBlend
Tbtus

8.2 Tableau overview

An overview of the agricultural submodel that is repeatedly included in FASOMGHG is given in Table 8-10. The columns represent variables, while the rows represent equations (e.g., resource constraints). This tableau shows a single period, single region version of the agricultural submodel.

This submodel maximizes welfare in the form of areas beneath the demand curves less than the areas beneath the explicit supply curves less other costs. This maximization occurs subject to

- Resource limits for land, water, labor, and AUM grazing
- Cconstraints on crop and livestock mixes
- Bbalances on primary, secondary and blended feed commodities
- GHG balances

The types of constraints are defined more precisely below.

In maximizing this objective the main manipulatable variables are:

- Crop production
- Livestock production
- Feed blending
- Land transformation
- Agricultural processing
- Domestic consumption
- Exports
- Imports
- GHG related payments.

These variables are defined more precisely below.

This single period submodel will be contained within any full FASOMGHG programming model multiple times with an instance occurring within every time period. The submodel is assumed to represent typical activity within each time period and the objective function contribution is treated as constant annuity during each of these generally five year periods. The submodel for the final time period is treated as if that level of activity were to persist forever.

8.2.1 Equations defined

The equations within this tableau are:

- Welfare -- Adds up agricultural consumers' plus producers' surplus. This consists of the area underneath the product demand curves arising from domestic consumption, exports and international consumption less the areas under the explicit supply curves from imports and international consumption on the product side along with labor, water and AUMs on the factor side. In addition, total cost is subtracted under a set of assumed infinitely elastic, fixed price supply curves of agricultural inputs used within crop and livestock production, processing, land transformation and transportation. We also add in the payments/taxes associated with net GHG emissions. The ***WELFAR*** GAMS implementation equation is represented by this tableau row.

- Crop land -- Limits crop land usage by tillage system to that available. The land use is limited to the initial agricultural endowment of crop land adjusted for land use chages to and from pasture and forest land. The land is used by the tillage choice variables. Limits on crop land use are defined on a subregional basis in periods when subregions are being used and on a regional basis otherwise. Cases within the ***AGTILLSTART*** and ***AGCANCHANGETILL*** GAMS implementation equations are represented by this tableau row.
- Tillage supply -- Limits acreage of each tillage system in use within the cropping variables to the acreage produced by the tillage choice variables. Limits crop land use by tillage system on a subregional basis when subregions are defined. Cases within the ***AGTILLUSE*** GAMS implementation equations are represented by this tableau row.
- Pasture Land -- Limits pasture land use to that available. The availability is the initial amount of agricultural pasture land adjusted for transformations to and from crop and forest land. This land is used by the livestock production variables. Limits pasture land use on a subregional basis when subregions are defined and regions otherwise. Cases within the ***AGPASTLANDEXCHANGE*** and ***AGLANDPASTURE*** GAMS implementation equations are represented by this tableau row.
- AUM Grazing -- Limits the usage of grazing land on an animal unit month (AUM) basis to that available. The grazing land is used by livestock production. The supply comes from a mixture of fixed price supply and upward sloping supply. This is defined on a subregional basis when subregions are being used for agricultural production. Cases within the ***AGRESBALANCE*** GAMS implementation equations are represented by this tableau row.
- Max Pub AUM -- Limits the maximum availability of fixed price AUM grazing largely reflecting public supply through grazing fees. Limits AUM grazing use on a subregional basis when subregions are being used for agricultural production. Cases within the ***AGRESMAX*** GAMS implementation equation are represented by this tableau row.
- Water -- Limits the water use to that available. The water is used by crop production. The water available comes from a mixture of sources. One is fixed price water (from BLM and other sources) that is only available up to a maximum quantity. The other is upward sloping supply curve component representing pumped water from ground and private surface water sources. Limits water use on a subregional basis when subregions are being used for agricultural production. Cases within the ***AGRESBALANCE*** GAMS implementation equations are represented by this tableau row.
- Fixed Water -- Limits the amount of fixed price water to a maximum quantity. Limits fixed water availability on a subregional basis when subregions are being used for

agricultural production. Cases within the ***AGRESMAX*** GAMS implementation equations are represented by this tableau row.

- Labor -- Limits the labor used to that available. Labor is used by the crop and livestock production variables. The labor available comes from a mixture of fixed price family labor that is available up to a maximum quantity and an upward sloping supply curve component of hired labor. The limits control the labor market at the geographic level of the 11 FASOMGHG regions. Cases within the ***AGRESBALANCE*** GAMS implementation equations are represented by this tableau row.
- Family Labor -- Limits the maximum availability of fixed price family labor again an 11 FASOMGHG region basis. Cases within the ***AGRESMAX*** GAMS implementation equations are represented by this tableau row.
- Primary Products -- Balances primary product usage so it cannot exceed primary product availability. Primary product usage arises through the combined effects of processing usage, feed blending usage, direct usage by livestock, domestic consumption, exports through the excess demand formulation and international trade. Availability comes from crop and livestock production and imports either from the excess supply formulation or the explicit international trade component. This constraint is defined on an 11 region basis when the commodity is regionalized and on a national basis. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Secondary Products -- Balances processed or secondary product usage so it cannot exceed secondary product availability. Secondary product usage arises through the combined effects of processing usage, feed blending usage, direct usage by livestock, domestic consumption, or exports. Availability coses from processing. This constraint is defined possibly on an 11 region basis and always on a national basis depending on the commodity. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- International mkt -- Balances foreign country/region markets do thir demand and outgoing international transportation is less than demand and incoming transport. The constraint is defined for the commodities which have explicit spatial international market modeling. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Blended feed -- Balances the usage of blended feeds with the amount produced. The constraint is defined on an 11 region basis. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Herd size -- Balances herd size for animals that can be treated with improved manure management against the number of animals treated with improved manure management

possibilities. The constraint is defined only for the categories of livestock that can be subjected to improved manure management for GHG emission reduction purposes. Limits the herd size on a subregional basis when subregions are being used for agricultural production. The ***AGMANUREMGT*** GAMS implementation equations are represented by this tableau row.

- Crop Mix -- Balances acreage by crop against the acreage allowed by the crop mix possibilities. The constraint is defined for each crop in the crop mixes on both an irrigated and total crop land basis. The geographic basis is the same as the active regional definition being used for agricultural production during a time period. The ***AGCRPMIXUP*** and ***AGCRPMIXLO*** GAMS implementation equations are represented by this tableau row.
- Crop mix convex -- Forces a convex combination of the crop mixes. The geographic basis is the same as the active regional definition being used for agricultural production during a time period. The GAMS implementation equations ***AGCRPMIXTOT*** are represented by this tableau row.
- Livestock Mix -- Balances the number of head by livestock against the distribution of head allowed by the livestock mix possibilities. The constraint is defined for each type of livestock for which a livestock mix is defined. The geographic basis is the same as the active regional definition being used for agricultural production during a time period. The ***AGLIVESTOCKMIXNAT*** GAMS implementation equations are represented by this tableau row.
- GHG net emissions -- Accumulates net GHG emissions by category and balances against the GHG payment variable by GHG account. That variable equals the total net emissions and is unrestricted in sign reflecting a possible net emission reduction available for payment and/or an emissions increase subject to emission payments. Net emission increments arise from sequestration possibilities under tillage choice, emissions related to crop or livestock production, savings from manure management, and emissions or offsets from agricultural processing (that includes biofuel feedstock usage). Forest and pasture sequestration is also accounted under the tillage choice and land use change variables. The ***GHGACCOUNTS*** GAMS implementation equations are represented by this tableau row.
- Forest land -- Forestry land use balance as explained in the forestry section above.

8.2.2 Variables defined

The variables present in the tableau are

- Tillage Choice -- Choice between tillage alternatives. They use crop land and supply tilled land for use in the crop production variables. They also have sequestration implications that fall in the GHG balance equations. Their presence allows for depiction of the dynamic trajectory of carbon sequestration under changes in tillage systems. These variables are defined for each crop land quality type, irrigation/dryland status and tillage alternative. These variables are defined on a subregional or regional basis depending on time period. The ***AGINITIALTILL*** and ***AGCHANGETILL*** GAMS implementation variables are represented by this tableau column.
- Crop Production -- Crop production possibilities. They use inputs as reflected within the objective function coefficient, tilled crop land, water, and labor while producing crop products. They also require land that falls within the allowed crop mixes and enter the GHG balance. In the GHG balance equation they enter several accounts including fossil fuel usage related emissions, nitrous oxide emissions and sequestration alterations by type of crop. They are defined by crop, crop land type, irrigation/dryland choice, fertilization alternative, and tillage alternative. These variables are defined on a subregional or regional basis depending on time period. The ***AGCROPBUDGET*** GAMS implementation variables are represented by this tableau column.
- Livestock Production -- Livestock production possibilities. They use inputs as reflected within the objective function coefficient, use pasture land, and use labor while producing livestock products. They also use some primary and secondary products directly as feed or intermediate animals (e.g. feeder pigs to finishing) and use blended feeds. They require that the animal distribution falls within the selected livestock mix, make animals available for improved manure management and enter the GHG balance. In the GHG balance, they enter several accounts including fossil fuel usage related emissions, enteric fermentation emissions and manure emissions. They are defined by animal type, livestock management alternative, and enteric fermentation alternative. These variables are defined on a subregional or regional basis depending on time period. The ***AGLVSTBUDGET*** GAMS implementation variables are represented by this tableau column.
- Manure Management -- Choice of improved manure management systems. They incur cost in the objective function, require that animals are present that can be treated and offset manure related emissions in the GHG balance. These variables are defined by type of animal and manure management system type. Geographically, they are defined on a subregional or regional basis depending on time period. The ***AGLVSTMANURE*** GAMS implementation variables are represented by this tableau column.

- Feed Blending -- Blending of livestock feeds from a number of different alternative formulas utilizing primary and secondary commodities. The resultant feeds are supplied for eventual consumption by the livestock production variables. These variables are defined by feed and feed blending alternative. Geographically they are defined on an 11 region basis. Cases within the ***AGREGPROCESS*** GAMS implementation variables are represented by this tableau column.
- Crop Mix -- Choice between a set of historically observed crop mixes. They implicitly represent many omitted resource constraints and other considerations. The variables supply a proportion of the land suitable for each different type of crop either on an irrigated or total crop acreage basis and enter the crop mix convexity equation. These variables are defined for a number of historical alternatives for irrigated crops and for total crops. Geographically they are defined on a subregional or regional basis depending on time period. The ***AGMIXR*** GAMS implementation variables are represented by this tableau column.
- Livestock Mix -- Choice between a set of historically observed livestock herd regional distributions by type of animal. They implicitly represent many omitted resource constraints and other considerations. These variables supply a proportion of the herd that appears in each region or subregion. These variables are defined by type of animal for each of a number of historical alternatives for livestock regional distributions. Geographically they are defined on a subregional or regional basis depending on time period. The ***AGNATMIX*** GAMS implementation variables are represented by this tableau column.
- Land to forest -- Land use change of crop or pasture land into forestry. When shifting crop land these variables reflect removal of land from the crop land constraints and supply into the forest land balance. When crop land is being shifted the entries in the subregion and land quality subcases contain coefficients that are proportional to their initial relative abundance. When pasture land is being shifted the coefficients reflect the removal of an acre from the pasture land equation and its supply into the forest land equation. These variables are defined far a single crop land and a pasture land case. Geographically they are defined on an 11 region basis. The ***LANDFROMAG*** and ***CONVRTFROMAG*** GAMS implementation variables are represented by this tableau column.
- Land from forest -- Land use change (deforestation) from forest land into crop or pasture land. These variables reflect supply of land into the agricultural land constraints and use of land from the forest land availability constraint. When crop land is being shifted the entries in the subregion and land quality subcases of the crop land equations contain

coefficients that are proportional to their initial relative abundance. When pasture land is being shifted the coefficients reflect the addition of one acre into the pasture land equation and its withdrawal from forest land. These variables are defined for a single crop land and a pasture land case. Geographically they are defined on an 11 region basis. The ***LANDTOAG*** and ***CONVRTTOAG*** GAMS implementation variables are represented by this tableau column.

- Land to pasture -- Land use change of crop land into pasture land. These variables reflect removal of land from crop land equations with coefficients that are proportional to their initial relative abundance in supply by quality type and then supply into the single homogeneous pasture land equation. These variables are defined geographically on the same basis as it is agricultural production by time period. Cases within the ***AGPASTLNDUSECHG*** GAMS implementation variables are represented by this tableau column.
- Land from pasture -- Land use change of pasture land into crop land. These variables reflect the supply of land into the subregion and land quality subcases of the crop land equations in a fashion proportional to their initial relative abundance and withdrawal from the pasture land equation. These variables are defined geographically on the same basis as it is agricultural production by time period. Cases within the ***AGPASTLNDUSECHG*** GAMS implementation variables are represented by this tableau column.
- AUM Supply -- Supply of AUM grazing from public and private sources. The publically supplied AUMs are assumed to be available at a fixed price (a grazinf fee) up to a maximum quantity. The private sources are supplied according to a supply function. The variables reflect the area under the supply function in the objective function, a supply into the AUM grazing equation and the use of any applicable maximum. These variables are defined on a subregional basis when subregions are being used for agricultural production. Cases within the ***AGRESSUPPLY*** and ***AGRESSEPSUPPLY*** GAMS implementation variables are represented by this tableau column.
- Water Supply -- Supply of water from fixed price and pumped sources. The fixed price supplied water is assumed to be available at a fixed price up to a maximum quantity and largely reflects the surface water supplied by the government (e.g. BLM water). The pumped sources are supplied according to a supply function. They represent private surface water markets and ground water. The variables reflect the area under the supply function in the objective function, a supply into the water equation and the use of any applicable maximum. These variables are defined on the regional basis being used for

agricultural production. Cases within the ***AGRESSUPPLY*** and ***AGRESSEPSUPPLY*** GAMS implementation variables are represented by this tableau column.

- Labor Supply -- Supply of labor from family and hired sources. The family labor is assumed to be available at a fixed reservation wage up to a maximum quantity. The hired labor is supplied according to a supply function. The variables reflect the area under the supply function in the objective function, a supply into the labor balance equation and the use of any applicable maximum. These variables are defined on an 11 region basis reflecting pooled regional labor markets. Cases within the ***AGRESSUPPLY*** and ***AGRESSEPSUPPLY*** GAMS implementation variables are represented by this tableau column.
- Processing -- Agricultural processing activity that transforms primary commodities into secondary commodities. The variables reflect the cost of processing in the objective function, the use of primary and some secondary products as inputs to processing and the creation of processed secondary products. The processing variables also enter the GHG balances reflecting GHG emissions from inputs used in processing and GHG offsets when they represent transformation of biofuel feedstocks into forms of bioenergy. These variables are defined by processing alternative and geographically are defined on either an 11 region or a national basis depending on the secondary commodity being manufactured. The ***AGPROCESS*** and cases within the ***AGREGPROCESS*** GAMS implementation variables are represented by this tableau column.
- Domestic Demand -- Domestic consumption of primary and secondary commodities. This includes the disappearance of commodities to the public, supermarkets or movement into processing alternatives that are not formally included in FASOMGHG. The variables have the area underneath the demand curve in the objective function and reflect a withdrawal of the commodity from the relevant primary or secondary balance at the national level. These variables are defined by commodity on a national basis. Cases within the ***AGDEMAND*** and the ***AGDEMANDS*** GAMS implementation variables are represented by this tableau column.
- Export Demand -- Export of goods which are specified with explicit rest of world excess demand equations. The variables have the area underneath the excess demand curve in the objective function and reflect withdrawal of the commodity from the relevant primary or secondary balance at the national level. These variables are defined by commodity on a national basis. Cases within the ***AGDEMAND*** and the ***AGDEMANDS*** GAMS implementation variables are represented by this tableau column.
- Import Supply -- Import of goods which are specified with explicit rest of world excess supply equations. The variables have the negative of the area underneath the import

excess supply curve in the objective function and reflect supply of the commodity into the primary or secondary balance. These variables are defined by commodity on a national basis. Cases within the ***AGSUPPLY*** and the ***AGSUPPLYS*** GAMS implementation variables are represented by this tableau column.

- International trade -- International transport between the US and foreign countries/regions and in between foreign countries/regions. These variables are defined for all pairs of movements allowed in the data between the US and foreign countries/regions and between the foreign countries/regions and themselves. The ***AGTRADE*** GAMS implementation variables are represented by this tableau column.
- Int. demand/supply -- Import and export of goods which are specified with explicit foreign country/region excess supply or demand equations. The variables have the area underneath the country level export excess demand or import excess supply curve in the objective function and reflect addition/withdrawal of the commodity in the foreign country/region commodity balance. These variables are defined by commodity for each relevant foreign country/region basis. Cases within the ***AGDEMAND, AGDEMANDS, AGSUPPLY,*** and ***AGSUPPLYS*** GAMS implementation variables are represented by this tableau column.
- GHG Payment -- Payments/taxes on net changes in GHG emissions. These variables are defined for each of the GHG accounts. Cases within the ***AMOUNTGHGS*** GAMS implementation variables are represented by this tableau column.

Table 8-10. Agricultural model tabular overview for a single period and region

	Tillage Choice	Crop Production	Livestock Production	Manure management	Feed Blending	Crop Mix	Livetock Mix	Land to forest	Land from forest	Land to pasture	Land from pasture	AUM Supply	Water Supply	Labor Supply	Processing	Domestic Demand	Export Demand	Import Supply	International trade	Int. demand / Supply	GHG Payment		
Welfare		-cc	-lc	-mc							-pc	-ac	-wc	-lbc	-prc	+di	+ei	-ii	-tc	+/-isc	+gp		
Crop land	+1							+1	-1	+1	-1											<	cla
Tillage supply	-1	+1																				=	0
Pasture Land			+lu					+1	-1	-1	+1											=	pla
AUM Grazing			+lg									-1										=	0
Max Pub AUM												+1										<	paum
Water		+cw											-1									=	0
Fixed Water													+1									<	Pwat
Labor		+cl	+ll											-1								=	0
Family Labor														+1								<	Plab
Primary Products		-cp	+/-lp		+fp										+pp	+1	+1	-1	+/-1			<	0
Secondary Products			+ls		+fs										+/-ps	+1	+1	-1				<	0
International mkt																			-/+1	+/-1		<	0
Blended feed			+lf		-1																	=	0
Herd size			+1	-1																		=	0
Crop Mix		+1				-mxc																=	0
Crop mix convex		+1				-mxs																=	0
Livestock Mix			+1				-la															=	0
GHG balance	-ts	+ce	+le	-me				-as	+as						+/-pg						-1	=	0
Forest land									-1	1												<	Fl

8.2.3 Coefficient definitions

The coefficients in the model are

cc -- the per acre cost of crop production which is the sum of the cost of using fixed price inputs
lc -- the per head cost of livestock production which is the sum of the cost of using fixed price inputs
mc -- the costs of the improved manure management systems
pc -- the cost of transforming pasture land into crop land
ac -- the area under the AUM supply curve
wc -- the area under the water supply curve
lbc -- the area under the labor supply curve
prc -- the cost of processing
di -- the area under the domestic demand curve
ei -- the area under the export demand curve
ii -- the area under the excess import supply curve
tc -- the cost of international transport
isd -- the area under the foreign excess demand and supply curves times minus one if this is an excess supply curve
gp -- the GHG payment rate
cla -- the amount of crop land initially available
lu -- pasture land use per head of livestock
pla -- the amount of pasture land initially available
lg -- the AUM grazing land requirement per head of livestock
paum -- maximum availability of public AUMs
cw -- the use of irrigation water per acre cropped
pwat -- maximum availability of fixed price water
cl -- the use of labor per acre of crop land
ll -- the use of labor per head of livestock
plab -- maximum availability of family labor
cp -- the primary product production per acre of crops
lp -- primary product production from livestock production and the primary products (crops directly fed) consumed directly in livestock production
fp -- use of primary products in blending one unit of feed
pp -- use of primary products per unit of processing
ls -- use of secondary products (soybean meal) directly in livestock production
fs -- use of secondary products in feed blending and the yield of the blended feeds
ps -- secondary product use in processing and the secondary product yield
lf -- usage of blended feed per head of livestock
mxc -- amount of each crop in the crop mix
mxs -- amount of all crops in the mix

la -- proportional amount of livestock in each active agricultural region during a period
ts -- sequestration under a tillage system per acre
ce -- emissions of GHGs by crop and GHG category
le -- emissions of GHGs by animal type and GHG category
me -- manure emissions offset per unit of emission system
pg -- processing net GHG emissions per unit of processing
as -- sequestration removed or added when land use change to or from forestry occurs
fl -- initial forest land

8.3 Details on features of the agricultural model

Now we show how particular aspects of agriculture are represented within the FASOMGHG programming model structure.

8.3.1 Crop production modeling

Table 8-11 portrays the FASOMGHG crop production model in a simplified one region, one time period, setting. The crop production alternatives vary by crop, crop land qualtity type, irrigated/dryland choice, fertilizer use and tillage system. It also shows the imposed relationships between the tillage choice and the crop production variables. Namely, in order to produce crops under a tillage system tilled acres must be supplied under that tillage system (where as discussed above there are three in the model). The tillage system choice variables are seperated to permit modeling of the dynamics of carbon sequestration under alterations in tillage systems (as discussed in the section immediately below). The tillage variables defined are both an initial tillage and a tillage change variable. The initial tillage variable is only defined for the first period and enters the GHG balance supplying a profile of current and future levels of carbon sequestration. The tillage change variables are defined for each time period and alter the GHG balance profile of sequestration from that time period to the end of the model.

The GHG balance entries for the production variable reflects production based emissions due to

- Changes in sequestration when longer lived perennials are involved.
- Fossil fuels used in tillage, planting, harvesting and other machinery operations
- Crop drying
- Irrigation
- Histosoils

- Nitrogen fertilization
- Rice production
- Fertilizer and pesticide manufacture
- Residue burning
- Sewage sludge usage
- Nitrogen fixing crops.

Now let us turn attention to a more precise definition of the tableau contents. The equations in this table 8-11 are

- Welfare -- Consumers' and producers' surplus. In this function the crop cost terms vary with crop and input usage. The GAMS implementation equation ***WELFAR*** is represented by this tableau row.
- Initial acres -- Limits initial starting amount of crop land to the initial inventory as allocated across irrigation status, tillage method employed and land type. The crop land usage by the initial tillage variables summed across the irrigation possibilities is constrained to not exceed the land by tillage class and type initially available. Geographically, this equation is defined on the same basis as is crop production and varies by time period. The GAMS implementation equation ***AGTILLSTART*** is represented by this tableau row.
- Tilled acres -- Balances amount of tilled acres with its use by tillage system, irrigation status, land type and time period. The land is used by the crop production variables supplied by either the initial tillage or the tillage change variables. Within these equations tillage changes are reflected where in an acre moves from one tillage type on one type of irrigated or dryland acreage to another tillage type possibly with a different irrigation status. Geographically this equation is defined on the same basis as is crop production. The constraint is defined for each explicit time period. The GAMS implementation equation ***AGTILLUSE*** is represented by these taleau rows.
- Can change till -- Limits the amount of tilled acres that can change tillage status. It is defined by tillage system, irrigation status and land type giving acres available to change the tillage during a particular time period. The land is supplied by the additional tillage choice and later the switch tillage variables. It is used by the tillage change variables. These equations are used to cause land changed into a tillage type to remain in that tillage type for a minimum amount of time before changing again. This restriction is enforced on all tillage changes after the initial choice. Geographically, this equation is defined on the same basis as is crop production. The constraint is defined for each explicit time period.

The GAMS implementation equation ***AGCANCHANGETILL*** is represented by this tableau row.

- Water -- Limits water use to water availability. Water availability modeling is portrayed in a simplistic fashion here and is more accurately and extensively discussed elsewhere. Within this constraint water use is restricted to irrigated crops. The coefficients for water use vary by crop and tillage system. Geographically, this equation is defined on the same basis as is crop production. The constraint is defined for each explicit time period. Cases within the ***AGRESBALANCE*** and ***AGRESMAX*** GAMS implementation equations are represented by this tableau row.
- Labor -- Limits labor use to labor availability. Labor availability modeling is portrayed in a simplistic fashion here and is more accurately and extensively discussed elsewhere. The coefficients for labor use vary by crop and tillage system. Geographically, this equation is defined on the 11 region basis. The constraint is defined for each explicit time period. Cases within the ***AGRESBALANCE*** and ***AGRESMAX*** GAMS implementation equations are represented by this tableau row.
- Primary Products -- Balances commodity supply with use. This constraint reflects yields from crop production and the disappearance of commodities in the marketplace. The constraint is defined for each crop commodity and can be defined either on a regional or national basis. Generally the commodities defined on a regional basis are those that are internationally traded, used in livestock feeds or used as biofuel feedstocks. The constraint is defined for each explicit time period. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Fertilizer -- this is not actually a FASOMGHG equation but is included for expositional purposes. This illustrates that fertilizer coefficients generally reflect changing amounts of fertilizer usage across crop and fertilizer strategies. These coefficients are collapsed into the objective function row by multiplying usage rates by fertilizer prices. Calculations within the implementation equation ***WELFAR*** are represented within this tableau row.
- GHG balance -- Net GHG emissions, sequestration and offsets from crop and tillage system usage and production are balanced with their eventual pricing. The constraint is defined for each GHG account on a national basis. Under crop production we have emissions from crop production associated with: (a) sequestration when longer lived perennials are involved; (b) fossil fuels used in tillage, planting, harvesting and other machinery operations; (c) crop drying; (d) irrigation; (e) histosoils; (f) nitrogen fertilization; (g) rice production; (h) fertilizer and pesticide manufacture; (i) residue burning; (j) sewage sludge usage; and (k) nitrogen fixing crops. Under the initial tillage system choice we have the sequestration trajectory for a particular tillage system. Under

the change till variable we have changes in the sequestration trajectory when tillage systems are altered. Under the land to and from pasture or forestry we reflect alterations in sequestration as moving land into crops removes it from the forest and pasture use GHG accounting and thus reflects a loss over there and a gain here. The constraint is defined for each explicit time period. Cases within the ***GHGACCOUNTS*** GAMS implementation equations are represented by this tableau row.

- Forest/Pasture land -- Land drawn from either the pasture or forest land parts of the model. It is more extensively discussed elsewhere.

The variables in table 8-11 are

- Crop production -- Acreage by crop land type allocated to each crop by fertilization strategy (of which there are three -- 70%, 85% and 100% of base levels), the three tillage alternatives, and dryland or irrigated status. The variable uses cost items, land by tillage status, water, labor and fertilizer. It creates a crop yield in the crop commodity balance row and has GHG net emission implications. Geographically the production variables are defined on a subregion or regional basis depending on the agricultural regions used in a particular time period. The variable is defined for each explicit time period. The ***AGCROPBUDGET*** GAMS implementation variables are represented by this tableau column.
- Initial till -- Assignment of initial agricultural land to tillage system and irrigation status. These variables use land from the initial allocation equation and supply it for crop production and also allow tillage change. Geographically these variables are defined on the same regional basis as are the crop production variables. The variable is defined for only for the first time period. The ***AGINITIALTILL*** GAMS implementation variables are represented by this tableau column.
- Switch tillage -- Tillage switches. Land is switched from one tillage system and irrigation status alternative to another. These variables use land from the period by period tillage availability equation and supply it into another. They require land suitable for a tillage change. Geographically these variables are defined on the same regional basis as are the crop production variables. The variable is defined for each time period. The ***AGCHANGETILL*** GAMS implementation variables are represented by this tableau column.
- Transform in land -- Land use change from pasture or forest land. These variables use land from pasture or forests and supply land across the different crop land quality types and subregions in a region. Land only moves into the conventional tillage, dryland

category. Geographically, these variables are defined only for a move of all crop land not by land type and only at a FASOMGHG 11 region level. The coefficients under these variables reflect the relative abundance of land by type and subregion. Thus, if 50% of the land in the PSW region were in Northern California and 50% in Southern California and each of those subregion that equal proportion of type 1 and type 2 land, then there would be four coefficients equaling -0.25's in the tableau in the tilled land available equation. The variable is defined for all of the time periods. Cases within the ***LANDTOAG*** and ***CONVRTTOAG*** GAMS implementation variables are represented by this tableau column.

- Transform out land -- Land use change to pasture or forest land. These variables supply land to pasture or forests and use land across the different crop land quality types and subregions in a region. Land only moves from the conventional tillage, dryland category. Geographically, these variables are defined only for a move of all crop land not by crop land quality type and only at a FASOMGHG 11 region level. The coefficients are the same as discussed under the transform in land variables discussed just above. The variable is defined for all of the time periods. Cases within the ***LANDFROMAG*** and ***CONVRTFROMAG*** implementation variables are represented by this tableau column.
- Commodity market -- Aggregate representation of the commodity markets as discussed elsewhere.
- GHG Payment -- GHG net emission payment submodel as discussed elsewhere. Cases within the ***AMOUNTGHGS*** GAMS implementation variables are represented by this tableau column.

Coefficients within table 8-11 are

cc -- cost of crop production which varies with crop management, crop, region, land type, and time period.
clt - cost of land transformation
cla -- initial endowment of land by land type and tillage system
cw -- water use by crop production which varies with crop management, crop, region, land type, and time period.
awater -- water availability and actually an indicator of a more complex water supply model structure
cl -- labor use by crop production which varies with crop management, crop, region, land type, and time period.
alabor -- labor availability and actually an indicator of a more complex labor supply model structure
cp -- yield from crop production which varies with crop management, crop, region, land type, and time period.

cf -- fertilizer use by crop production which varies with crop management, crop, region, land type, and time period.
ce -- net GHG emissions by crop production which varies with crop management, crop, region, land type, and time period.
cs -- net GHG sequestration by crop tillage system which varies with tillage system, irrigation alternative, region, and land type.
oland -- land in pasture and forests and an indicator of other submodels using those lands.

Table 8-11 Tableau illustrating static crop production and tillage choice

	Crop 1 low fert, conv till, dry land type 1	Crop 1 normal fert, conv till, dry land type 1	Crop 1 low fertilizer, min till, dry land type 1	Crop 1 normal fert, min till, dry land type 1	Crop 1 low fert, conv till, dry land type 1	Crop 1 normal fert, conv. till, dry land type 1	Crop 1 low fertilizer, min till, dry land type 1	Crop 1 normal fert, min till, dry land type 1	Initial till conv on dry land type 1	Initial till min on dry land type 1	Initial till conv on irrigated land type 1	Initial till min on irrigated land type 1	Switch conv dry to minimum dry land type 1	Switch conv dry to minimum irrig land type 1	Crop 1 low fert, conv till, dry land type 2	Initial till conv on dry land type 2	Transform in land	Transform out land	Commodity market	GHG Payment	
Welfare	-	-	-	-	-	-	-	-							-		-	-	+	+	
Initial acres conventional land type 1									+		+										≤ cla
Initial acres minimum till land type 1										+1		+1									≤ cla
Initial acres minimum till land type 2																+1					≤ cla
Tilled acres dryland conventional land type 1	+	+							-1				+	+			-	+l			≤ 0
Tilled acres dryland minimum till land type 1			+1	+1						-1			-1								≤ 0
Tilled acres irrigated conventional land type 1					+1	+1					-1										≤ 0
Tilled acres irrigated minimum till land type 1							+1	+1				-1		-1							≤ 0
Tilled acres dryland conventional land type 2															+1	-1	- lt	+l t2			≤ 0
Can change till dryland conventional land type 1									-1	-1			+	+							≤ 0
Water					+	+	+	+													≤ Awater
Labor	+ cl	+ cl	+ cl	+ cl	+ cl	+ cl	+ cl	+ cl							+ cl						≤ Alabor
Primary Products	-	-	-	-	-	-	-	-							-				+		≤ 0
Fertilizer	+	+	+	+	+	+	+	+							+						
GHG balance	+	+	+	+	+	+	+	+	-	-	-	-	-	-	+	-				-1	= 0
Forest/Pasture land																	+	-1			≤ Oland

8.3.1.1 Tillage choice

While table 8-11 illustrates several important features regarding crop production, tillage choice and tillage system change, the dynamics of these features are not shown therein. Consequently, table 8-12 was created to illustrate the dynamic features of tillage change across the land related variables/constraints and the GHG balance. A number of key points are illustrated:

- The initial tillage choice variable supplies land for use by crop production in the initial and all future time periods. Thus, when land initially is conventionally tilled then the initial tillage variable provides conventionally tilled into the land available for crop production equations in time periods 1, 2, 3 and all subsequent periods. Simultaneously, these variables supply acreage into the land that can be subjected to a change from conventional tillage in the current and subsequent periods.
- The initial tillage variable provides a current and future carbon sequestration trajectory. This incorporates the dynamics of tillage based sequestration reflecting accumulation and attainment of a new equilibrium where carbon gains effectively saturate.
- The tillage change tillage variables use land from a previous tillage status and move it into its new tillage status. In the tableau that when land is changed from conventional tillage to minimum till we have +1 in the conventional row and -1 in the minimum tillage row.
- The model can reflect both tillage intensification and deintensification with this tableau containing changes back from minimum tillage to conventional tillage.
- The tillage change variables enter the GHG balance for the current and future periods altering the sequestration profile with coefficients that reflect the sequestration differences observed when the tillage system is altered. These coefficients can be either positive or negative depending on whether the tillage intensity tillage is being increased or decreased. Data from the EPIC or CENTURY crop simulation models are used to specify such numbers.
- When a tillage change is pursued in a period it uses up available acreage from the constraint on land permitted to have a tillage change in that period and all subsequent periods. This can be seen in the constraints for periods 1 and 3.
- The source of land available for a tillage change can either be from (a) initial tillage choice, (b) current or past land use changes from forest or pasture or (c) from a tillage change in previous period.

- When tillage is changed that the land is made available for subsequent tillage changes only with a lag. For example, in the tableau, when tillage is altered in time period 1 the land does not become available for subsequent changes until time period 3. The reason for use of such a restriction is that it allows us to accurately portray sequestration dynamics including the approach to saturation. We employ the assumption that once tillage is changed it cannot be altered again for a minimum of 20 years.
- Table 8-12 shows the differences in the way the model handles land use between the forest and agricultural sectors.
  - Fundamentally in the forest sector the land use change variables do not try to reflect the multi-period implications of land transfers in the forest land equation. Rather this is handled within the multi-period forestry production variables.
  - When the land is moved into agriculture then we must reflect multi-period implications across the agricultural submodels for each FASOMGHG time periods. Thus when land is moved in time period 1 it makes land available for cropping use in time periods 1, 2, and 3.
- We restrict land movements so they can only come into or out of the conventionally tilled dryland case. Land can in turn be moved into other tillage or irrigation systems since the model allows an immediate tillage change.
- When land is moved in a period it only supplies land in later periods.
- The GHG accounts are dynamic and are stocks not flows.
  - Thus, we have payments for the GHG accounts in each time period.
  - We accumulate GHG emissions. This means that emissions in the first time period also enter the GHG balance in the second and subsequent time periods.
- The net effect of cropping on the GHG balance involves both crop production effects and tillage effects. The tillage effects are initially composed of the sequestration profile arising from the initial tillage choice variable. But these effects can be subsequently corrected as tillage changes are put into place employing the tillage switch variable. Such tillage changes can reflect either intensification or deintensification.

Now suppose we turn our attention to a more formal definition of structural elements. The equations in this tableau are:

- Welfare -- the welfare equation as discussed above. The GAMS implementation equation ***WELFAR*** is represented by this tableau row.

- Initial acres -- Limits initial acreage by type of tillage system to that available as has been discussed above. This has region, land type, and tillage system dimensions. The GAMS implementation equation ***AGTILLSTART*** is represented by this tableau row.
- Tilled acres -- Balances use and supply of acres by tillage system and irrigation status. This land is used by crop production. In the tableau this is portrayed in a simplistic fashion but actually would have regional, land type, irrigated/dryland, and tillage system dimensions as well as time period. The GAMS implementation equation ***AGTILLUSE*** is represented by this tableau row.
- Can change till -- Controls the amount of acreage that can be subjected to a tillage system change. This is used to facilitate carbon accounting and reduce model size. Tillage system changes may only occur after the land has been subjected to that tillage system for 20 years so that we may assume that the sequestration quantity is mature. This constraint that same dimensions as detailed acreage constraint just above. The GAMS implementation equation ***AGCANCHANGETILL*** is represented by this tableau row.
- GHG balance -- Adds up the cumulative stock of GHG emissions, sequestration and offsets and balances it against the GHG payments variable. This constraint is defined for the various GHG accounts in all time periods. Cases within the ***GHGACCOUNTS*** GAMS implementation equations are represented by this tableau row.
- Forest land -- the constraint that reflects the land availability in land use within the forestry model as discussed above.

The variables in this tableau are

- Crop prod. -- Amount of crop production undertaken as discussed above. This variable is defined by region, crop, land type, tillage system, fertilization alternative, irrigation/dryland and time period. These variables use land by tillage system that is available in the time period for which the cropping variable is defined. The ***AGCROPBUDGET*** GAMS implementation variables are represented by this tableau column.
- Initial tillage -- Amount of land initially entering each of tillage/irrigation system possibility by region. These variables use land from the initial tillage limit equation, then supply land for use by cropping in each subsequent time period, supply land available to switch tillage in each subsequent time period and reflect the initial sequestration profile in the GHG balance equations. The ***AGINITIALTILL*** GAMS implementation variables are represented by this tableau column.
- Switch tillage -- Amount of land switching from and to each of the tillage/irrigation system possibilities by region. These variables use land from the tilled acreage equation

for the tillage system and irrigation possibility that land will be switched from then supply it into the corresponding equation for the new tillage system and irrigation status. They also use land on which tillage may switched and subsequently supply land on which tillage can be switched in the future with some lag as discussed above. They enter the GHG balance equations reflecting the dynamic shift in the sequestration trajectory relative to the tillage and irrigation system combination from which land is being withdrawn. The ***AGCHANGETILL*** GAMS implementation variables are represented by this tableau column.

- Transfer land -- Amount of land use change from forestry both from and to pasture and forestry. These variables use land from the previous land use balance equation and place acreage into the balance for the conventional tillage system under dryland status. They also permit both immediate and subsequent switches from the tillage/irrigation system combination. Much more about these variables is discussed above and more will appear in the next chapter. Cases within the ***LANDTOAG*** and ***CONVRTTOAG*** GAMS implementation variables are represented by this tableau column.
- GHG Payment -- Net GHG payments as has been discussed above. Cases within the ***AMOUNTGHGS*** GAMS implementation variables are represented by this tableau column.

The coefficients in this tableau meriting definition are

cc -- the carbon sequestration trajectory under conventional tillage and the chosen irrigation alternative that varies by region, land type, tillage system and elapsed time since the beginning of the model.

cm -- the carbon sequestration trajectory under minimum tillage and the chosen irrigation alternative that varies by region, land type, tillage system and elapsed time since the beginning of the model.

cg -- change in the carbon sequestration trajectory when switching from conventional tillage under the chosen irrigation status to minimum tillage under another irrigation status that varies by region, land type, tillage system, irrigation status and elapsed time since the switch.

cl -- change in the carbon sequestration trajectory when switching from minimum tillage under the chosen irrigation status to conventional tillage under another irrigation status that varies by region, land type, tillage system, irrigation status and elapsed time since the switch.

as -- change in sequestration when land moves in that aloso would be matched by losses in pasture soil accounting.

Table 8-12 Tableau illustrating dynamics of tillage choice

	Crop prod. dryland conv. till period 1	Crop prod dryland min. till period 1	Crop prod. dryland conv. till period 2	Crop prod dryland min. till period 2	Crop prod. dryland conv. till period 3	Crop prod dryland min. till period 3	Initial till conv on dryland	Initial till min on dryland	Switch conv dry to min dry period 1	Switch min. till dry to conv. pd 1	Switch conv dry to min dry period 2	Switch min. till dry to conv. pd 2	Switch conv dry to min dry period 3	Switch min. till dry to conv. pd 3	Transfer land into crops period 1	Transfer land into crops period 2	Transfer land into crops period 3	GHG Payment in period 1	GHG Payment in period 2	GHG Payment in period 3		
Welfare	-	-	-	-	-	-												+	+	+		
Initial acres conventional							+1														<	*
Initial acres minimum till								+1													<	+
Tilled acres dryland conventional period 1	+1						-1		+1	-1					-1						<	0
Tilled acres dryland minimum till period 1		+1						-1	-1	+1											<	0
Tilled acres dryland conventional period 2			+1				-1		+1	-1	+1	-1			-1	-1					<	0
Tilled acres dryland minimum till period 2				+1				-1	-1	+1	-1	+1									<	0
Tilled acres dryland conventional period 3					+1		-1		+1	-1	+1	-1	+1	-1	-1	-1	-1				<	0
Tilled acres dryland minimum till period 3						+1		-1	-1	+1	-1	+1	-1	+1							<	0
Can change till dryland conventional land period 1							-1		+1						-1						<	0
Can change till dryland minimum till period 1								-1		+1											<	0
Can change till dryland conventional land period 2							-1				+1				-1	-1					<	0
Can change till dryland minimum till period 2								-1				+1									<	0
Can change till dryland conventional land period 3							-1			-1			+1		-1	-1	-1				<	0
Can change till dryland minimum till period 3								-1	-1					+1							<	0
GHG balance period 1	+	+					+cc	+cn	+cg	-cl					+as			-1			=	0
GHG balance period 2	+	+	+	+			+cc	+cn	+cg	-cl	+cg	-cl			+as	+as			-1		=	0
GHG balance period 3	+	+	+	+	+	+	+cc	+cn	+cg	-cl	+cg	-cl	+cg	-cl	+as	+as	+as			-1	=	0
Forest land in period 1															+1						<	+
Forest land in period 2																+1					<	+
Forest land in period 3																	+1				<	+

8.3.1.2 Land transfer dynamics

When crop land is transferred in or out it possesses a number of notable characteristics that deserve mention. Namely when crop land transfers out to pasture in a particular time period that land is removed from crop land use and made available for pasture not only in the time period of transfer, but also in all subsequent periods. Furthermore, when land transfers out of the land quality differentiated crop land into the single homogeneous category pasture land it is assumed to transfer in a distribution proportion to the way the different qualities of crop land were initially populated. In particular, if initially 25% of the land in a region fell into the wetland category then when land transfers from crop land the transferred acre will withdraw 25% of an acre from the wetland category along with 75% of an acre from the other three quality classes in appropriate proportions.

Similar practices are employed when land transfers into crop land from pasture. Namely land it is removed in the time period of the transfer and all subsequent time periods. Furthermore, land is placed into the various crop land land quality accounts in proportion to the initial proportional shares by land quality class.

When crop land transfers occur from and to forestry, the land flows come from and to the high quality forest site index. Land moving in supplies crop land in the current and all subsequent time periods and withdraws land from the CROPFOR or FORCROP categories. When land transfers out from crop land it goes into the balance for afforested land in the CROPFOR forest land category. Crop land is also removed from or added to the agricultural crop land balance in the time period of transfer and all subsequent time periods. Transfers are again in proportion to the initial population distribution across land quality classes.

8.3.1.3 Crop mixes

As discussed above, aggregation problems are avoided by requiring the crops in a region to fall within the mix of crops observed. The model is constrained so that for each area the crop mix falls within one of those observed in the past 40 years. Both irrigated and dryland mixes are present. The way the crop mixes are implemented is illustrated in table 8-13. This table employs example numbers in representing how the crop mixes constrain the feasible levels of the crop production variables. In particular, concentrating for the moment only on the total acreage crop mix constraints, notice how the first four crop production variables require that acres be available for the particular crop being grown in the total acres crop mix by crop constraint. Note that it also uses acreage from the total crop acres convexity equation.

The crop mix variables depict historical alternatives of which two contrived ones are shown. These make acreage available for each crop in the total crop mix by crop equations. These variables also make the sum of the acreage across all crops in the mix available in the total crop mix convexity equation. Collectively, the intersection of these constraints makes the only feasible cropping alternatives to have somewhere between 30% (30/100) and 25% (60/150) of the acreage devoted to crop 1 with the rest devoted to crop 2.

In the more general model the crop mix constraints cover all of the crops excluding the biofuels which have not historically been produced. There are also almost 35 crop mix alternatives for each region and the data within the tableau are drawn from historical records and are in the file ***data_agcropmix.gms***.

Broadening our examination to cover both the total acreage and irrigated acreage crop mix restricutions that are imposed in FASOMGHG, note that the total acreage crop mix constraints imposes the crop mixes for the sum of dryland plus irrigated dryland acreage while the irrigated mix constraints only act on the irrigated crop production possibilities.

More formally the equations in this tableau are

- Tillage supply -- Limits the acreage of each tillage system in use within the cropping variables to the acreage produced by the tillage choice variables. Limits crop land use by tillage system on a subregional basis when subregions are defined. Cases within the ***AGTILLUSE*** GAMS implementation equations are represented by this tableau row.
- Total acres crop mix by crop -- Balances the acreage by crop against the total acreage allowed by the crop mix possibilities. The constraint is defined for each relevant crop on a total careage by crop basis. The geographic basis is the same as the definition being used for crop production during each time period. Cases within the ***AGCRPMIXUP*** and ***AGCRPMIXLO*** GAMS implementation equations are represented by this tableau row.
- Crop mix convexity -- Forces a convex combination of the total acres covered of a crop in the mix. The geographic basis is the same as that used for crop production during a time period. Cases within the GAMS implementation equations ***AGCRPMIXTOT*** are represented by this tableau row.

- Irrigated acres crop mix by crop -- Balances acreage by crop against the total irrigated acreage allowed by the crop mix possibilities. The constraint is defined for each relevant crop on a total irrigated crop land use basis. The geographic basis is the same as is being used for crop production during a time period. Cases within the ***AGCRPMIXUP*** and ***AGCRPMIXLO*** GAMS implementation equations are represented by this tableau row.
- Irrigated acres crop mix convexity -- Forces a convex combination of the irrigated acres crop mix by crop. The geographic basis is the same as is being used for crop production during a time period. Cases within the GAMS implementation equations ***AGCRPMIXTOT*** are represented by this tableau row.

The variables in this tableau are

- Crop Production -- Crop production possibilities. They use tilled crop land and also require land that falls within the appropriate crop mix and crop mix convexity constraints. They are defined by crop, crop land quality type, irrigation/dryland choice, fertilization alternative, and tillage alternative. These variables are defined on a subregional or regional basis depending on time period. The ***AGCROPBUDGET*** GAMS implementation variables are represented by this tableau column.
- Total acreage crop mix -- Choice across a set of historically observed crop mixes. They implicitly represent many omitted resource constraints and other considerations. The variables supply a proportion of the land suitable for each different type of crop and the total acres across all crops in the crop mix convexity equation. These variables are defined for a number of historical alternatives for total regional/subregional crop acreage. Geographically they are defined on a subregional or regional basis depending on time period. Cases within the ***AGMIXR*** GAMS implementation variables are represented by this tableau column.
- Irrigated acreage crop mix -- Choice across a set of historically observed irrigated crop mixes. They implicitly represent many omitted resource constraints and other considerations. The variables supply a proportion of the land suitable for each different type of irrigated crop and the total irrigated acres across all crops into the crop mix convexity equation. These variables are defined for a number of historical alternatives for total regional/subregional irrigated crop acreage. Geographically they are defined on a subregional or regional basis depending on time period. Cases within the ***AGMIXR*** and ***AGMIXR2*** GAMS implementation variables are represented by this tableau column.

Coefficients appearing within this tableau are purely illustrative and are actually drawn from the crop mix data in the GAMS file ***data_agcropmix.gms*** from 1970 to 2002.

Table 8-13 Tableau illustrating crop mix modeling

	Crop prod. Crop 1 dryland	Crop prod. Crop 1 irrigated	Crop prod. Crop 2 dryland	Crop prod. Crop 2 irrigated	Total crop mix alternative 1	Total crop mix alternative 1	Irrigated crop mix alternative 1	Irrigated crop mix alternative 1		
Tilled acres dryland										
Tilled acres irrigated		+1		+1					<	0
Total acres mix -- crop 1	+1	+1			-30	-60			=	0
Total acres mix -- crop 2			+1	+1	-70	-90			=	0
Convexity for total acres mix	+1	+1	+1	+1	-100	-150			=	0
Irrigated acres mix -- crop 1		+1					-20	-20	=	0
Irrigated acres mix -- crop 2				+1			-20	-30	=	0
Convexity for irrigated acres mix		+1		+1			-40	-50	=	0

8.3.2 Livestock production/Feed blending

The other major agricultural production component involves livestock production and associated feed blending. Table 8-14 provides a simplified but somewhat comprehensive example of the livestock production and feed blending component again on a single period, single region basis. There we portray the basic livestock related agricultural resources of pasture, labor, and AUM grazing along with raw crop commodities and blended feeds. We also see multiple types of livestock being produced generating multiple products, some of which are intermediate products into further livestock production. For example, feeder pigs are produced as an intermediate input to a hog finishing operation. The tableau also contains examples of enteric fermentation alternatives for dairy and methane related manure management alternatives.

Another feature illustrated in the model is livestock feed blending and use. The livestock production alternatives directly use primary crop commodities like corn and sorghum as feeds but also use blended feeds as illustrated in the case of egg grain feed. The feed blending process is also shown using crop commodities. The tableau shows two alternative variables that each make egg layer blended grain feed which both incur some degree of costs and use different amounts of crop commodities to blend the homogeneous commodity egg layer grain feed. This reflects commodity substitution depending on the relative prices of the commodities used.

The tableau also illustrates livestock production involvement in the GHG accounting balances. Livestock generate direct emissions related to factors such as fossil fuel usage but also have emissions related to enteric fermentation and manure while being involved with pasture land sequestration. The pasture land sequestration involves accounting of the cumulative sequestration on pasture land in use and idle pasture land. In terms of enteric fermentation, there are multiple production possibilities for selected livestock types that alter feed additives, feeding patterns and usage of pasture based on the alternatives discussed in Johnson et al. For manure management we use EPA data to represent alternative manure management systems and the potential of altering methane emissions for animals produced with wet manure handling systems - hogs and dairy.

Resource usage patterns in the tableau illustrate several animal dependent FASOMGHG characteristics. In particular, while all livestock production systems can potentially use all resources, the data do not reflect this. For example, in the pasture land and AUM grazing cases only the more extensive operations are shown to use such. Similarly, the blended feeds are tailored to certain types of animals and are not used by others. Finally, things like enteric fermentation and manure management only apply to certain classes of animals.

Now suppose we turn attention to a more formal definition of the tableau contents. The equations in the tableau are:

- Welfare -- the welfare equation that is maximized as discussed above. The subcomponent regarding livestock includes usage of variable inputs by livestock production along with the costs of manure management, feed blending, and land transformations. The tableau also crudely shows the objective function contributions that occur in the product market, the costs of factor supply and the payments to net changes in the GHG accounts. The GAMS implementation equation ***WELFAR*** is represented by this tableau row.
- Pasture land -- Balances the disposition of pasture land by fate and with the supply of pasture land from the initial endowment less the net effect of transformations from/to forests and crops. In terms of pasture land disposition, both the active use of pasture land

by livestock and idle pasture land are considered. This allows accounting for sequestration on both used and idled land. Geographically, this equation is defined for each time period on the same regional basis as is agricultural production across time periods. The GAMS implementation equation ***AGPASTLANDEXCHANGE*** is represented by this tableau row.

- Pasture land in use -- Balances pasture land used by livestock with pasture land in use variables. This allows accounting for sequestration on pasture land whether it is idled or not. Geographically, this equation is defined on the same regional basis as is agricultural production. The GAMS implementation equation ***AGLANDPASTURE*** is represented by this tableau row.
- Labor -- Balances labor used by livestock production with labor supply as will be discussed below. This equation is defined for 11 FASOMGHG regions for each time period. Cases within the GAMS implementation equation ***AGRESBALANCE*** are represented by this tableau row.
- Grazing -- Balances AUM grazing used by livestock production variables with AUM grazing supply as discussed below. Geographically, this equation is defined on the same regional basis as is agricultural production. Cases within the GAMS implementation equation ***AGRESBALANCE*** are represented by this tableau row.
- Commodity balance -- Balances usage against supply for the primary, secondary and blended feed commodities. The commodities covered include crops, livestock intermediate products (feeder pigs, calves, etc.), livestock final primary products (e.g. eggs, raw milk, fed hogs, cull sows), secondary products and blended feeds (egg layer grain feed). Only a simplified portrayal of the product market is present here that ordinarily would include processing, domestic consumption, imports, exports and international trade. The tableau shows how livestock activities can be involved in producing and using the commodity in an equation. For example, in the feeder pig commodity balance we see production of feeder pigs by the feeder pig production activity and their use in the hog finishing activity. This equation is defined for each of the FASOMGHG time periods and for each primary, secondary and blended feed commodity on a national or regional basis. Generally a regional basis is used for the crops used in feeding, blended feeds, and intermediate livestock products. The GAMS implementation equation ***AGPRODBAL*** is represented by this tableau row.
- Head for manure management -- Limits the number of head that can be subject to improved manure management to the number of head produced under the production variables and the proportional share of wet manure management systems that could be improved. This equation is defined by animal type subject to wet manure management

(swine and dairy) and for multiple manure management system alteration possibilities based on applicable percentage of the herd. Geographically this equation is defined on the same regional basis as is agricultural production. The GAMS implementation equation ***AGMANUREMGT*** is represented by this tableau row.

- Livestock mix -- Controls the regional distribution of livestock around the country. This will be elaborated on below. This equation is defined by type of animal on the same regional basis as is agricultural production. The GAMS implementation equation ***AGLIVESTOCKMIXNAT*** is represented by this tableau row.
- Crop/forest land - Represents the cropping and forestry parts of the model as discussed under those sections in this and the previous chapter.
- Maximum land to crop -- Limits the quantity of pasture land that can be transformed to crops based on land suitability. Again this constraint is defined for all time periods on the same geographical basis as is agricultural production. The GAMS implementation equation ***AGMAXPASTURETOCROP*** is represented by this tableau row.
- GHG balance -- Adds cumulative GHG emissions, sequestration stock and biofuel related offsets then balances that sum against the GHG payments variable. This constraint is defined for various GHG accounts including the ones highlighted here. The livestock related ones involve enteric fermentation, manure management and pasture sequestration. For manure management this shows that the management alternatives offset the emissions from base levels where the net effect is their difference. The equation is defined for all explicit time periods in FASOMGHG on the same regional basis as is livestock production. Cases within the ***GHGACCOUNTS*** GAMS implementation equation are represented by this tableau row.

The variables appearing in this tableau are

- Livestock Production -- Livestock production possibilities. They use inputs as reflected within the objective function coefficient, pasture land, labor and AUM grazing while producing primary products like eggs, feeder pigs, and finished hogs. They also use some intermediate livestock products as inputs to higher order livestock production processes. Feeds including crop commodities and blended feeds are used along with, while not shown here, secondary products (like soybean meal). They also require that the animal distribution falls within the selected livestock mix, make animals available for improved manure management and enter the GHG balance. In the GHG balance equation, the livestock production variables enter various accounts including fossil fuel usage related emissions, enteric fermentation related emissions and manure emissions. They are defined by animal type, livestock management alternative, and enteric fermentation alternative. These variables are defined on a subregional or regional basis depending on time period. The ***AGLVSTBUDGET*** GAMS implementation variables are represented by this tableau column.

- Manure Management -- Employment of improved manure management systems. They incur cost in the objective function, require animals that can be treated, limit the number of animals treated by each system to a maximum and offset manure related emissions in the GHG balance. These variables are defined by type of animal and manure management system type. Geographically they are defined on a subregional or regional basis depending on time period. The ***AGLVSTMANURE*** GAMS implementation variables are represented by this tableau column.
- Feed Blending -- Blending of livestock feeds via a number of different alternative formulas. Primary and secondary commodities are used according to the formula. The resultant feeds are supplied for livestock consumption. These variables are defined by feed and feed blending alternative. Geographically, they are defined on an 11 region basis by time period. Cases within the ***AGREGPROCESS*** GAMS implementation variables are represented by this tableau column.
- Livestock Mix -- Choice between a set of historically observed livestock herd regional distributions by type of animal. They implicitly represent many omitted resource constraints and other considerations. These variables supply a proportion of the herd that appears in each region or subregion. These variables are defined by type of animal for each of a number of historical alternatives for livestock regional distributions. Geographically they are defined on the same basis as is livestock production. The ***AGNATMIX*** GAMS implementation variables are represented by this tableau column.
- Use pasture -- Amount of pasture land used by livestock. These variables are equated with the use computed underneath the livestock production variables and fall into the pasture land sequestration GHG balance equations. The variables are defined for each of the FASOMGHG time periods and on the same regional basis as is agricultural production. The GAMS ***AGUSEPASTURE*** variables are represented by this tableau column.
- Land to forest/crop land -- Land use change from pasture to crop land or forests. These variables withdraw from the pasture land equations and supply into the crop or forest land equations as discussed in the crop and forest modeling sections. Land movement to crop land is subject to a maximum suitability restriction and a transformation cost. GHG accounting entries remove sequestration from the pasture land account and if moving to crop land place sequestration into the crop land sequestration account. These variables are defined geographically on the same basis as is agricultural production by time period.

Cases within the ***AGPASTLNDUSECHG***, ***LANDFROMAG*** and ***CONVRTFROMAG*** GAMS implementation variables are represented by this tableau column.

- Land from forest/crop land -- Land use change to pasture from crop or forest land. These variables reflect supply into the pasture land equations and withdrawal of land from the crop land or forest land equations as discussed in the crop land and forest modeling sections. GHG accounting entries place sequestration into the pasture land account and if moving from crop land remove sequestration from the crop land sequestration account. These variables are defined geographically on the same basis as it is agricultural production and by time period. Cases within the ***AGPASTLNDUSECHG***, ***LANDTOAG*** and ***CONVRTTOAG*** GAMS implementation variables are represented by this tableau column.
- Idle pasture -- Amount of pasture land in the inventory that is idle. These variables are equated with pasture land available less the use by livestock activities and fall into the pasture land sequestration GHG balance equations. The variables are defined for each of the FASOMGHG time periods and on the same regional basis as is agricultural production. The GAMS ***AGIDLELANDPASTURE*** variables are represented by this tableau column
- Resource Supply -- Supply of labor and AUM grazing. The variables reflect the cost of the supply in the objective function, a supply into the appropriate resource equation and the use of any applicable maximum. These variables are defined on a subregional or regional basis depending on time period and item being supplied. Cases within the ***AGRESSUPPLY*** and ***AGRESSEPSUPPLY*** GAMS implementation variables are represented by this tableau column.
- Product market -- these variables represent the more general product market as discussed above and below.
- GHG Payment -- Net GHG payments as discussed above. Cases within the ***AMOUNTGHGS*** GAMS implementation variables are represented by this tableau column.

The coefficients appearing in this tableau are

cl -- the costs of livestock production which is the sum of the variable inputs used times their prices plus any other cost factors
cm -- the cost of alternative manure management systems
cb -- the cost of feed blending including the cost of any commodities consumed that are not explicitly modeled

clt -- the cost of land transformation particularly those for transforming pasture land into crop land
apast -- the initial availability of agricultural pasture land
lu -- livestock usage of pasture land
lb -- livestock usage of labor
lg -- livestock usage of AUM grazing
ldf -- livestock usage of primary crop commodities directly for feed usage
bc -- feed blending usage of primary crop and while not shown here secondary processed commodities
y -- the yield of primary commodity from production of a livestock alternative
iu -- the intermediate usage of livestock primary commodities as inputs to higher order livestock production alternatives
fu -- the usage of blended feed commodities as inputs to livestock production alternatives
lm -- the proportional distribution of the livestock herd by region or subregion for this animal type and particular livestock herd distribution mix alternative.
ee -- enteric fermentation emissions by animal
me -- manure related emissions by animal under base manure management
cm -- reduction in manure related emissions obtained when treating a given number of animals under a given manure management alternativemaxtran -- maximum regional amount of land that can be transferred from pasture land to crop land at the model initiation
le -- other GHG emissions by animal

Table 8-14 Tableau illustrating livestock production and feed blending

	Produce eggs	Produce feeder pigs	Farrow to finish	Finish hogs	Cow calf	Dairy base production	Dairy with enteric	Dairy manure manage 1	Dairy manure manage 2	Blend Egg grain diet 1	Blend Egg grain diet 2	Blend other feeds	Livestock mix	Use pasture	Land into crops or forest	Land from crops or forest	Idle pasture	Commodity Mkt	Resource supply	GHG Payment		
Welfare	-cl	-cl	-cl	-cl	-cl	-cl	-cl	-cm	-cm	-cb	-cb	-cb			-clt	-clt		+	+	+		
Pasture land														+1	+1	-1	+1				<	Apast
Pasture land in use					+lu	+lu	+lu							-1							=	0
Labor	+lb	+lb	+lb	+lb	+lb	+lb	+lb												-		<	0
Grazing					+lg	+lg	+lg												-		<	0
Commodity balance – Corn	+ldf	+ldf	+ldf	+ldf	+ldf	+ldf	+ldf			+bc	+bc	+bc						+			<	0
Commodity balance – Sorghum	+ldf	+ldf	+ldf	+ldf	+ldf	+ldf	+ldf			+bc	+bc	+bc						+			<	0
Commodity balance – Eggs	-y																	+			<	0
Commodity balance -- Raw milk						-y	-y											+			<	0
Commodity balance – Calves					-y																<	0
Commodity balance -- Feeder pigs		-y		+iu																	<	0
Commodity balance - Finished hogs			-y	-y														+			<	0
Commodity balance - Cull sows		-y	-y															+			<	0
Commodity balance Egg protein mix	+fu											-1									<	0
Commodity balance Egg grain mix	+fu									-1	-1										<	0
Commodity bal Other blended feeds		+fu	+fu	+fu	+fu	+fu	+fu					-1									<	0
Head for manure manag – dairy						-1	-1	+1	+1												<	0
Livestock mix	+1	+1	+1	+1	+1	+1	+1						-lm								<	0
Crop/forest land															-1	+1					<	0
Maximum land to crop															-1	+1					<	Maxtran
GHG balance enteric					+ee	+ee	+ee													-1	=	0
GHG balance manure	+me	+me	+me	+me	+me	+me	+me	-cm	-cm											-1	=	0
GHG balance pasture sequestration														+ps			+ps			-1	=	0
GHG balance other	+le	+le	+le	+le	+le	+le	+le													-1	=	0

8.3.2.1 Livestock mixes

An important FASOMGHG element involves the way that the livestock mixes influence the regional distribution of livestock production. Years ago experience with the ASM predecessor during Burton's Ph.D. thesis indicated that the model had difficulties with developing an appropriate interregional allocation of livestock. Cases were found where the model solution reflected production of all the hogs in the whole model in the state of Georgia. Subsequently, a livestock mix regional distribution approach was incorporated that required the livestock herd to be distributed across the country in a fashion consistent with the historic interregional herd distribution. Interregional distributions are included from the last 30+ years.

Table 8-15 portrays the interrelationship between livestock production and the livestock mixes. The tableau illustrates two regions for two types of animals with two alternative mixes for each livestock type. Livestock production in a region requires that a mix be adopted that reflects production of that type of livestock in that region. Each livestock mix alternative implies particular interregional distribution of the herd. The mix contraint involves the sum of the animals across all regional alternatives for that animal type. This constraint implicitly considers omitted processing and production capacity constraints along with other factors which are behind the interregional livestock distribution.

Now suppose we turn attention to a more formal definition of the tableau contents. The equations therein are:

- Livestock resources -- Land, labor and AUM grazing resources faced by livestock production as discussed above. These equations are defined for the same geographic regions as are agricultural production.
- Livestock mix -- Control the regional distribution of livestock around the country. This equation is defined by type of animal and time period on the same regional basis as is agricultural production. The GAMS implementation equation ***AGLIVESTOCKMIXNAT*** is represented by this tableau row.

The variables appearing in this tableau are

- Livestock Production -- Livestock production possibilities. These use resources and require animal specific livestock mixes. They are defined by animal type, livestock management alternative, and enteric fermentation alternative. These variables are defined on a subregional or regional basis depending on time period. The ***AGLVSTBUDGET*** GAMS implementation variables are represented by this tableau column.

- Livestock Mix -- Choice between a set of historically observed livestock herd regional distributions by type of animal and time period. They implicitly represent many omitted resource constraints and other considerations. These variables supply a proportion of the herd in each region or subregion. These variables are defined by type of animal for each of a number of historical alternatives for livestock regional distributions. Geographically they are defined on a subregional or regional basis depending on time period. The ***AGNATMIX*** GAMS implementation variables are represented by this tableau column.

Coefficients appearing within this tableau are purely illustrative and are actually drawn from the livestock mix data from the GAMS file ***data_agnatmix.gms*** from 1970 to 2002.

Table 8-15 Tableau illustrating livestock mix modeling

	Livestock prod. region 1 animal type 1 base	Livestock prod. region 1 animal type 1 enteric	Livestock prod. region 1 animal type 2	Livestock prod. region 2 animal type 1 base	Livestock prod. region 2 animal type 1 enteric	Livestock prod. region 2 animal type 2	Livestock mix alt animal type 1 alternative 1	Livestock mix alt animal type 1 alternative 2	Livestock mix alt animal type 1 alternative 1	Livestock mix alt animal type 1 alternative 2		
Livestock production resources region 1	+	+	+								<	+
Livestock production resources region 2				+	+	+					<	+
Livestock mix -- animal 1, region 1	+1	+1					-30	-60			=	0
Livestock mix -- animal 1, region 2				+1	+1		-70	-90			=	0
Livestock mix -- animal 1, region 1			+1						-20	-20	=	0
Livestock mix -- animal 1, region 2						+1			-20	-30	=	0

8.3.2.2 Dynamics

The livestock submodel has the same dynamic characteristics as does the crop model. Namely, livestock activity in each of the five year FASOMGHG periods is assumed to be repeated at the same annual level for each year in the five year period. There is no dependency between adjacent five year periods other than through land transfers.

Land transfers are modeled with dynamic characteristics as discussed above relative to the agricultural cropping submodel. Namely, when pasture land is transferred to crop land in a particular time period that land is removed from pasture land use and made available for cropping not only in the time period of transfer, but also in all subsequent periods. Furthermore, when land transfers out of the single homogeneous category pasture land into the land quality differentiated crop land it is assumed to transfer in a distribution proportion to the way the different qualities of crop land were initially populated. In particular, if initially 25% of the land in a region fell into the wetland category then when land transfers into crop land the transferred pasture land acre will supply 25% of an acre into the wetland category along with 75% of an acre into the other three quality classes in appropriate proportions.

Similar practices are also employed when land transfers from crop land into pasture land. Namely, when the model transfers an acre from crop land into pasture land it is removed in the time period of the transfer and all subsequent time periods. Furthermore, land is withdrawn from the various crop land land quality accounts in proportion to the initial proportional shares by land quality class.

When pasture land transfers occur from and to forestry, the land flows come from and to the medium quality forest site index. Land moving in supplies pasture land in the current and all subsequent time periods and precludes reforestation of land in the PASTFOR and FORPAST forest land categories. When land transfers out from pasture land it goes into the balance for afforested land in the PASTFOR forest land category. Pasture land is also removed from the agricultural pasture land balance in the time period of transfer and all subsequent time periods.

8.3.3 Processing and feed blending

Agricultural processing and feed blending is modeled to reflect commodity substitution possibililities or to reflect demand for different product forms. In terms of substitution agriculture commodities are frequently substitutable as inputs to the production of other products or in blended feeds. For example, beet sugar is a perfect substitute for cane based sugar while sorghum can be substituted for corn in feed blending. In terms of demand for different product forms, agricultural products are frequently processed into a mix of secondary products. For example, soybeans are crushed into soybean meal and soybean oil which face different markets. The set odf processing alternatives used was selected to reflect important processing substitution and demand form possibilities.

Some of the processing alternatives are modeled on a regional basis some on a national basis. The processing alternatives represented on a national basis and the commodities they manufacture and use are listed in table 8-16 below. The regional processing alternatives are listed in table 8-17.

Table 8-16 National processing alternatives and the commodities they involve

FASOMGHG name for national processing alternative	Secondary product manufactured	Primary and secondary commodities used in manufacture
makeAmCheese	AmCheese	Cream, SkimMilk
makeOtCheese	OtCheese	Cream, SkimMilk
makeHFCS	HFCS	CornStarch
makeBeverages	Beverages	HFCS, RefSugar
makeConfection	Confection	HFCS, RefSugar
makeBaking	Baking	HFCS, RefSugar
makeCanning	Canning	HFCS, RefSugar
makeEthanol	Ethanol	CornStarch
makeMktGasBlend	MktGasBlend	Ethanol
makeSubGasBlend	SubGasBlend	Ethanol
makeDextrose	Dextrose	CornStarch
StockSteerCalftoFeed	StockedCalf	StockedSCalf
StockHeiferCalftoFeed	StockedCalf	StockedHCalf
StockSteerYearlingtoFeed	StockedYearling	StockedSYearl
StockHeiferYearlingtoFeed	StockedYearling	StockedHYearl
HeiferYearlingSlaughter	NonFedSla	StockedHYearl
SteerYearlingSlaughter	NonFedSla	StockedSYearl
NFSlatonF	NonFedBeef	NonFedSla
FSlatofBe	FedBeef	FeedlotBeefSlaughter
DClfToBeef	SteerCalve	DairyCalves
CleanWool	WoolClean	Wool
makeCSyrup	CornSyrup	CornStarch
RefSugar1	CaneRefini	Sugarcane
RefSugar2	RefSugar	Sugarbeet
CaneRefine	RefSugar	CaneRefini
HogToPork	Pork	HogsforSlaughter
BroilChick	Chicken	Broilers

TurkeyProc	Turkey	Turkeys
SowToPork	Pork	CullSow
ButterPow	NonFatDryM, Butter	Milk
FluidMlk1	FluidMilk, Cream	Milk
EvapoMilk	EvapCondM	Milk
FluidMlk2	Cream, SkimMilk	Milk
IceCream1	IceCream	Milk, Cream, NonFatDryM
IceCream2	IceCream	Milk, Cream, SkimMilk
Cottage	CottageChe	Milk, Cream, SkimMilk
Frozen-Pot	FrozenPot	Potatoes
DeHydr-Pot	DriedPot	Potatoes
CHIP-POT	ChipPot	Potatoes
JuiceOrang	OrangeJuic	OrangeProc90box
JuiceGrpft	GrpfrtJuic	GrpfrtProc85box

Table 8-17 Regional non feed blending processing alternatives and the commodities they involve

FASOMGHG name for regional non feed processing alternative	**Secondary product manufactured**	**Primary and secondary commodities used in manufacture**
SoyCrush1	SoybeanMeal, SoybeanOil	Soybeans
WetMill	GlutenFeed, CornStarch, CornOil	Corn
Gluttosbm	SoybeanMeal	GlutenFeed
SwitchgrassToElec	Tbtus	SwitchGrass
HybridpoplarToElec	Tbtus	HybrdPoplar
WillowToElec	Tbtus	Willow
SwitchgrassToEthanol	Ethanol	SwitchGrass
HybridpoplarToEthanol	Ethanol	HybrdPoplar
WillowToEthanol	Ethanol	Willow

In addition livestock feed blending is embedded within the regional processing activities and involves the products, alternatives and inputs identified in Table 8-18. Details on this blending are presented in the section on livestock feeding above.

Table 8-18 Regional feed blending processing alternatives and the feeds made plus commodities they involve

FASOMGHG name for regional feed processing alternatives that blend this feed	Blended feed product manufactured	Primary and secondary commodities used in manufacture
stkpromix0, stkpromix2	StockPro0	SoybeanMeal
beefbases, beefalt1s, beefalt2s, beefalt3s,	CatGrain0	Corn, SoftWhiteWheat,

beefalt4s, beefalt5s, beefalt6s, beefalt7s, beefbasew, beefalt1w, beefalt2w, beefalt3w, beefalt4w, beefalt5w, beefalt6w, beefalt7w, beefbaset, beefalt4t, beefalt5t, beefalt6t, beefalt7t, beefbased, beefalt1d, beefalt2d, beefalt3d, beefalt4d, beefalt5d, beefalt6d, beefalt7d		HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
catpro1, catpro3	HighProtCa	SoybeanMeal
cowbases, cowalt1s, cowalt2s, cowalt3s, cowalt4s, cowalt5s, cowalt6s, cowalt7s, cowbasew, cowalt1w, cowalt2w, cowalt3w, cowalt4w, cowalt5w, cowalt6w, cowalt7w, cowbaset, cowalt4t, cowalt5t, cowalt6t, cowalt7t, cowbased, cowalt1d, cowalt2d, cowalt3d, cowalt4d, cowalt5d, cowalt6d, cowalt7d	CowGrain0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
cowpromix0, cowpromix2	CowHiPro0	SoybeanMeal
basemix1s, alt1mix1s, alt2mix1s, alt3mix1s, alt4mix1s, alt5mix1s, alt6mix1s, alt7mix1s, basemix1w, alt1mix1w, alt2mix1w, alt3mix1w, alt4mix1w, alt5mix1w, alt6mix1w, alt7mix1w, basemix1t, alt1mix1t, alt2mix1t, alt3mix1t, alt4mix1t, alt5mix1t, alt6mix1t, alt7mix1t, basemix1d, alt1mix1d, alt2mix1d, alt3mix1d, alt4mix1d, alt5mix1d, alt6mix1d, alt7mix1d	FinGrain0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
finpromix0, finpromix6	FinProSwn0	SoybeanMeal
hogbases, hogalt1s, hogalt2s, hogalt3s, hogalt4s, hogalt5s, hogalt6s, hogalt7s, hogbasew, hogalt1w, hogalt2w, hogalt3w, hogalt4w, hogalt5w, hogalt6w, hogalt7w, hogbaset, hogalt1t, hogalt2t, hogalt3t, hogalt4t, hogalt5t, hogalt6t, hogalt7t, hogbased, hogalt1d, hogalt2d, hogalt3d, hogalt4d, hogalt5d, hogalt6d, hogalt7d	FarGrain0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
farpromix0, farpromix6	FarProSwn0	SoybeanMeal
basemix2s, alt1mix2s, alt2mix2s, alt3mix2s, alt4mix2s, alt5mix2s, alt6mix2s, alt7mix2s, basemix2w, alt1mix2w, alt2mix2w, alt3mix2w, alt4mix2w, alt5mix2w, alt6mix2w, alt7mix2w, basemix2t, alt1mix2t, alt2mix2t, alt3mix2t, alt4mix2t, alt5mix2t, alt6mix2t, alt7mix2t, basemix2d, alt1mix2d, alt2mix2d, alt3mix2d, alt4mix2d, alt5mix2d, alt6mix2d, alt7mix2d	FPGGrain0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
fdppromix0, fdppromix6	FPGProSwn0	SoybeanMeal
dairybases, dairyalt1s, dairyalt2s, dairyalt3s, dairyalt4s, dairyalt5s, dairyalt6s, dairyalt7s, dairybasew, dairyalt1w, dairyalt2w, dairyalt3w, dairyalt4w, dairyalt5w, dairyalt6w, dairyalt7w, dairybaset, dairyalt1t, dairyalt2t, dairyalt3t, dairyalt4t, dairyalt5t, dairyalt6t, dairyalt7t, dairybased, dairyalt1d, dairyalt2d, dairyalt3d, dairyalt4d, dairyalt5d, dairyalt6d, dairyalt7d	DairyCon0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
brobases, broalt1s, broalt2s, broalt3s, broalt4s, broalt5s, broalt6s, broalt7s, brobasew, broalt1w, broalt2w, broalt3w, broalt4w, broalt5w, broalt6w,	BroilGrn0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat,

broalt7w, brobaset, broalt4t, broalt5t, brobased, broalt1d, broalt2d, broalt3d, broalt4d, broalt5d, broalt6d, broalt7d		HardRedSpringWheat, Sorghum, Barley
brlpromix0, brlpromix4	BroilPro0	SoybeanMeal
polbases, polalt1s, polalt2s, polalt3s, polalt4s, polalt5s, polalt6s, polalt7s, polbasew, polalt1w, polalt2w, polalt3w, polalt4w, polalt5w, polalt6w, polalt7w, polbaset, polalt4t, polalt5t, polbased, polalt1d, polalt2d, polalt3d, polalt4d, polalt5d, polalt6d, polalt7d	TurkeyGrn0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
trkpromix0, trkpromix4	TurkeyPro0	SoybeanMeal
eggbases, eggalt1s, eggalt2s, eggalt3s, eggalt4s, eggalt5s, eggalt6s, eggalt7s, eggbasew, eggalt1w, eggalt2w, eggalt3w, eggalt4w, eggalt5w, eggalt6w, eggalt7w, eggbaset, eggalt4t, eggalt5t, eggbased, eggalt1d, eggalt2d, eggalt3d, eggalt4d, eggalt5d, eggalt6d, eggalt7d	EggGrain0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
eggpromix0, eggpromix5	EggPro0	SoybeanMeal
bases, alt1s, alt2s, alt3s, alt4s, alt5s, alt6s, alt7s, basew, alt1w, alt2w, alt3w, alt4w, alt5w, alt6w, alt7w, baset, alt1t, alt2t, alt3t, alt4t, alt5t, alt6t, alt7t, based, alt1d, alt2d, alt3d, alt4d, alt5d, alt6d, alt7d	SheepGrn0	Corn, SoftWhiteWheat, HardRedWinterWheat, DurhamWheat, HardRedSpringWheat, Sorghum, Barley
shppromix0, shppromix2	SheepPro0	SoybeanMeal

Processing activity modeling in FASOMGHG is relatively simplistic largely concentrating on:

- Primary and secondary commodity usage,
- Secondary or blended feed commodity yield and
- All other costs.

Thus, for example, in portraying soybean crushing the FASOMGHG processing activity uses one unit of soybeans and generates a given number of pounds of soybean meal and tons of soybean oil at a cost. The cost is usually the observed price differential between the value of the outputs and the value of the inputs according to Agricultural Statistics. The tableau in table 8-19 portrays elements of processing:

Table 8-19 Tableau illustrating processing

	Wet mill corns	Crush soybeans	First stage cane refinancing	Cane sugar to sugar	Refine sugar beets	Make fluid milk	Slaughter fed beef	Make HFCS	Make confectionaries with sugar	Make confectionaries with HFCS	Substitute gluten feed for soy meal	Commodity Mkt	
Welfare	-c	-c	-c	-c	-c	-c	-c	-c	-c	-c	-c	+	
Commodity balance -- Corn	+ci											+	≤ 0
Commodity balance -- Soybeans		+ci										+	≤ 0
Commodity balance -- Sugarcane			+ci									+	≤ 0
Commodity balance -- Sugar beets					+ci							+	≤ 0
Commodity balance -- Feedlot beef							+ci					+	≤ 0
Commodity balance -- Raw milk						+ci						+	≤ 0
Commodity balance -- Soybean meal		-cy									-cy	+	≤ 0
Commodity balance -- Soybean oil		-cy										+	≤ 0
Commodity balance -- Refined cane			-cy	+ci								+	≤ 0
Commodity balance -- Refined sugar				-cy	-cy				+ci			+	≤ 0
Commodity balance -- Fluid milk						-cy						+	≤ 0
Commodity balance -- Cream						-cy						+	≤ 0
Commodity balance -- Corn starch	-cy							+ci				+	≤ 0
Commodity balance -- Gluten feed	-cy										+ci	+	≤ 0
Commodity balance -- Corn oil	-cy											+	≤ 0
Commodity balance -- HFCS								-cy		+ci		+	≤ 0
Commodity balance -- Fed beef							-cy					+	≤ 0
Commodity balance -- Confectionaries									-cy	-cy		+	≤ 0

where the equations depicted are

- Welfare -- the welfare objective function that is maximized as discussed above. In this function the processing cost terms vary with product created, along with primary and secondary commodity usage. The GAMS implementation equation ***WELFAR*** is represented by this tableau row.
- Commodity balance -- Balances usage against supply for the primary, secondary and blended feed commodities. The commodities depicted in the tableau include
  - primary commodities from crops (corn, soybeans), and livestock (feedlot beef, raw milk)
  - secondary products created by processing (soybean meal through soybean crushing or confectionaries throuch use of sweetners)

Only a portion of the variables appearing within these equations are portrayed here as for example the product market that ordinarily would include processing, domestic consumption, imports, exports and international trade. The tableau shows how livestock activities can be involved in producing and using the commodity in an equation. This equation is defined for each time periods and for each primary, secondary and blended feed commodity on a national or regional basis. Generally a regional basis is used for the crops used in feeding, blended feeds, and intermediate livestock products. The GAMS implementation equation ***AGPRODBAL*** is represented by this tableau row.

The variables in this tableau are

- Processing -- Amount of agricultural processing activity. Such activity transforms primary commodities into secondary commodities. The variables reflect processing cost in the objective function, use of primary and some secondary products as inputs to the production process and eventual creation of processed secondary products. These variables are defined by processing alternative and on either an 11 region or a national basis depending on the secondary commodity being manufactured. The ***AGPROCESS*** and cases within the ***AGREGPROCESS*** GAMS implementation variables are represented by this tableau column.
- Commodity market -- Supply and consumption markets for the commodities.

The terms in this tableau are

- c -- the per unit costs of agricultural processing
- ci -- the per unit usage of commodities by agricultural processing
- cy -- the per unit yield of secondary commodities by agricultural processing

Generally the processing activities reflect the usage of primary and some intermediate secondary commodities as inputs to the production of other secondary commodities. For example, in the tableau we see processing alternatives that involve

- Usage of primary commodities (though the rows for corn through raw milk) and resultant conversion into some mixture of secondary commodities (i.e., soybeans to soybean meal and oil).
- Usage of a single primary commodity and its transformation through use of the fixed coefficient into a related to secondary commodity (i.e., the tableau illustrates conversion of beef on the hoof to carcass beef and conversion of sugar cane to raw cane sugar). Incorporation of this type of processing allows us to represent production of the raw

commodities at farm gate prices and then consumption of processed commodities in common units like carcass weight of pork, fed beef, chicken or turkey.
- Use of secondary commodities to create other secondary commodities like the use of cornstarch to create HFCS.
- Use of more than one possible mixture of input commodities to create the same final secondary commodity. For example the tableau illustrates manufacture of confectionaries using HFCS or refined sugar as a sweetener

The processing activities are also used to implement the regional feed blends as listed in the table above and the livestock production section.

8.3.4 Factor markets

Three fundamental approaches are taken to agricultural factor market modeling. Each approach applies to different types of factors. These approaches and the markets to which they apply are

- Land modeling of crop and pasture land
- Water, AUM grazing and labor factor supply that includes explicit factor supply curves
- Purchased inputs that are assumed made available according to an infinitely elastic, fixed price, supply curve

Each will be discussed separately

8.3.4.1 Land modeling of crop and pasture land

The land markets have been discussed above and will be more extensively discussed in the chapter on intersectoral land and commodity movements below. The only statement we will make here is that these land markets are subject to a fixed total availability of land but with the possibilities of land use change between crop, pasture and forest usages. Developed usage also constitutes an added demand.

8.3.4.2 Water, AUM grazing and labor which have explicit factor supply curves

Explicit supply curves are present for irrigation water, AUM grazing and labor. The supply curves have two components

- A component of factor supply at a fixed price up to a maximum availability
- A component of factor supply according to an upward sloping supply curve

Table 8-20 shows an overview of this availability while details regarding the individual markets for irrigation water, AUM grazing and labor are discussed in sections just below.

The equations in this tableau are

- Welfare - Adds up the quantity that is maximized when the FASOMGHG programming model is solved. The quantity added up consists of the area underneath the product demand curves arising from consumption less the areas under the import supply curves along with the area under the labor, water and AUMs factor supplies. The factor supply related objective function terms reflect the two factor supply components. The first involves price times quantity for the fixed price factor supplies. The second consists of the area underneath the upward sloping factor supply for that factor. In addition price times quantity is subtracted for a set of other agricultural inputs used within crop, livestock, and processed product production. We also add in net GHG payments. The ***WELFAR*** GAMS implementation equation is represented by this tableau row.
- Crop land -- Limits crop land usage to that available. The land use is limited to the initial agricultural endowment of crop land adjusted for transformations to and from pasture land and transformations to and from forest land as discussed above. This is defined on a subregional basis when subregions are defined across tillage systems. Cases within the ***AGTILLSTART, AGTILLUSE*** and ***AGCANCHANGETILL*** GAMS implementation equations are represented by this tableau row.
- Pasture Land -- Limits pasture land usage to that available. The availability is the initial amount of agricultural pasture land adjusted for transformations to and from crop land and transformations to and from forest land. This land is used by the livestock production variables. Limits pasture land use on a subregional basis when subregions are defined. Cases within the ***AGPASTLANDEXCHANGE*** and ***AGLANDPASTURE*** GAMS implementation equations are represented by this tableau row.
- AUM Grazing -- Limits the usage of grazing land to that made available on an animal unit month (AUM) basis. AUMs are used by livestock production. Supply comes from a mixture of public fixed price supply and private upward sloping supply. This is defined on a subregional basis when subregions are defined. Cases within the ***AGRESBALANCE*** GAMS implementation equations are represented by this tableau row.
- Max fixed price AUMs -- Limits the maximum availability of fixed price AUM grazing. Limits use on a subregional basis when subregions are defined. Cases within the ***AGRESMAX*** GAMS implementation equations are represented by this tableau row.
- Water -- Limits irrigation water use to that available. Irrigation water is used by crop production. The water available comes from a mixture of fixed price water (from BLM and other sources) that available up to a maximum quantity and an upward sloping supply curve component representing pumped water from ground and private surface water sources. Limits use on a subregional basis when subregions are defined. Cases within the ***AGRESBALANCE*** implementation equations are represented by this tableau row.

- Fixed Water -- Limits the amount of fixed price water to a maximum quantity. Limits fixed water availability on a subregional basis when subregions are defined. Cases within the ***AGRESMAX*** GAMS implementation equations are represented by this tableau row.
- Labor -- Limits labor used to that available. Labor is used by the crop and livestock production. Labor available comes from both fixed price family labor that is available up to a maximum quantity and an upward sloping supply curve component of hired labor. Limits use an an 11 FASOMGHG region basis. Cases within the ***AGRESBALANCE*** GAMS implementation equations are represented by this tableau row.
- Family Labor -- Limits maximum availability of fixed price family labor. The constraint limits family labor availability on an 11 FASOMGHG region basis. Cases within the ***AGRESMAX*** GAMS implementation equations are represented by this tableau row.
- Primary Products -- Balances primary product usage so it cannot exceed primary product availability. Primary product usage arises through the combined effects of processing usage, feed blending usage, direct feed usage by livestock, domestic consumption, exports through the excess demand formulation and international trade. Availability comes from crop and livestock production plus imports either from the excess supply formulation or the explicit international trade component. This constraint is defined on either an 11 region or a national basis depending on the commodity. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Secondary Products -- Balances processed product usage so it cannot exceed availability. Processed product usage arises through processing, feed blending, direct feeding to livestock, domestic consumption, or exports. This constraint is defined on either an 11 region or national basis depending on the commodity. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- National inputs -- Balances national input usage for inputs that are assumed infinitely available at fixed price with supply. National input usage arises through the combined effects of crop, livestock and processed product production. The constraint is defined on a national basis and is generally not included in the model but rather collapsed into the objective function unless a maximum national input limit is specified. Cases within either the ***WELFAR*** or ***AGPROCESSMAXPURCHINPUT*** GAMS implementation equations are represented by this tableau row

The variables within this tableau are

- Crop Production -- Crop production possibilities. They use inputs that are infinite elastic in supply as reflected within the objective function coefficient while also using crop land, irrigation water, and labor. They produce primary crop products. These variables are defined on a subregional or regional basis depending on time period. The ***AGCROPBUDGET*** implementation variables are represented by this tableau column.

- Livestock Production -- Livestock production possibilities. They use inputs that are infinite elastic in supply as reflected within the objective function coefficient while using AUM grazing, pasture land, and labor. The produce primary livestock products. They also use some primary and secondary products directly as feed or intermediate animal inputs and use blended feeds. These variables are defined on a subregional or regional basis depending on time period. The ***AGLVSTBUDGET*** GAMS implementation variables are represented by this tableau column.
- Fixed price Water Supply -- Supply of irrigation water that is fixed in price. That water is assumed to be available at the fixed price up to a maximum quantity and largely reflects the surface water supplied by the government like that from the BLM. The variables reflect the fixed price of such supply in the objective function and supply into the water equation. They are subject to maximum availability. These variables are defined on a subregional or regional basis depending on time period. Cases within the ***AGRESSUPPLY*** implementation variables are represented by this tableau column.
- Upward sloping water supply -- Supply of irrigation water from an upward sloping supply curve. That water largely reflects private surface water and pumped ground water. The variables reflect the negative of the area under the supply curve in the objective function and supply into the water equation. They are subject to maximum availability. These variables are defined on a subregional or regional basis depending on time period. Cases within the ***AGRESSUPPLY*** implementation variables are represented by this tableau column.
- Fixed price AUM grazing supply -- Supply of AUM grazing that is fixed in price. This AUM grazing is assumed to be available at a fixed price up to a maximum quantity and largely reflects the AUM grazing supplied by the government through grazing fees. The variables reflect the fixed price of the supply in the objective function and a supply into the AUM grazing equation. They are subject to a maximum availability. These variables are defined on a subregional or regional basis depending on time period. Cases within the ***AGRESSUPPLY*** implementation variables are represented by this tableau column.
- Upward sloping AUM grazing supply -- Supply of AUM grazing from an upward sloping supply curve. That water largely reflects private market AUMs. The variables reflect the area under the supply curve in the objective function and a supply into the AUM grazing equation. They are subject to a maximum availability. These variables are defined on a subregional or regional basis depending on time period. Cases within the ***AGRESSUPPLY*** implementation variables are represented by this tableau column.
- Processing -- Amount of processing activity. The variables reflect the cost of processing in the objective function, the use of primary and some secondary products as inputs to the production process and the eventual creation of processed secondary products. These variables are defined by processing alternative and geographically are defined on either

an 11 region or a national basis depending on the commodity being manufactured. The ***AGPROCESS*** and cases within the ***AGREGPROCESS*** GAMS implementation variables are represented by this tableau column.

- Family Labor Supply -- Supply of labor from family sources. The family labor is assumed to be available at a fixed reservation wage to up to a maximum quantity. The variables reflect the reservation wage as a cost of the supply in the objective function, a supply into the labor balance equation and use against the applicable maximum. These variables are defined on an 11 region basis reflecting pooled regional labor markets. Cases within the ***AGRESSUPPLY*** implementation variables are represented
- Hired Labor Supply -- Supply of labor from hired sources. Hired labor is supplied according to a supply function. The variables reflect the area under the supply curve in the objective function and a supply into the labor balance equation. These variables are defined on an 11 region basis reflecting pooled regional labor markets. Cases within the ***AGRESSUPPLY*** GAMS implementation variables are represented by this column.
- National input supply -- Supply of fixed price national inputs on a national basis. These inputs are assumed to be infinitely available at a fixed price. They are balanced against the usage of these national inputs in crop, livestock and processed product production. The portrayal in the tableau is purely conceptual as these items are calculated into the objective function cost terms for the production and processing variables
- Commodity Market -- this tableau column represents the more general commodity market including domestic consumption, exports and imports.

The coefficients in the model are

- cc -- the per acre cost of crop production which is the sum of the cost of using fixed price inputs
- lc -- the per head cost of livestock production which is the sum of the cost of using fixed price inputs
- wf - the per unit to price of the fixed price water supply
- wi - the area under the upward sloping water supply curve
- ac - the per unit price for the fixed price AUM supply
- ai - the area under the AUM supply curves
- cp - the per unit cost of processing
- lw - the reservation wage for family labor
- li - the area under the hired labor supply curve
- cw - the use of irrigation water by crops
- Fpw - maximum availability of fixed price water
- lg - the AUM grazing land requirement per head of livestock

- Fpa - maximum availability of fixed price AUMs
- clb - the use of labor per acre of crop production
- alb - the use of labor per head of livestock production
- fpl - maximum availability of fixed price labor
- cy - the primary product production per acre of crop production
- lny - accounts on a per head of livestock basis for the primary product production and the primary products (crops directly fed) consumed directly in livestock production
- pp - use of primary products per unit of processing
- ps -- accounts on a per unit of processing basis for the secondary yield from processing
- ci -- usage of national inputs per acre of crop production
- li -- usage of national inputs per head of livestock production
- pi -- usage of national inputs per unit of processing

Components of this tableau merit explanation as discussed below.

Table 8-20 Tableau illustrating factor supply

	Crop production -- subregion 1	Livestock production -- subregion 1	Fixed price water -- subregion 1	Supply curve water -- subregion 1	Fixed price AUMS -- subregion 1	Supply curve AUMS -- subregion 1	Crop production -- subregion 2	Livestock production -- subregion 2	Fixed price water -- subregion 2	Supply curve water -- subregion 2	Fixed price AUMS -- subregion 2	Supply curve AUMS -- subregion 2	Processing -- FASOMGHG region	Family labor -- FASOMGHG region	Supply curve labor -- FAS region	National input supply	Commodity Mkt		
Welfare	-cc	-lc -c	-wf	-wi	-ac	-ai	-cc	-lc -c	-wf	-wi	-ac	-ai	-cp	-lw	-li	-1	+		
Crop land - subregion 1	+1																	<	+
Pasture land - subregion 1		+li																<	+
Water - subregion 1	+cw		-1	-1														<	0
Max fixed price water -- subregion 1			+1															<	Fpw
AUM grazing - subregion 1		+lg			-1	-1												<	0
Max fixed price AUMs -- subregion 1					+1													<	Fpa
Crop land - subregion 2							+cl											<	0
Pasture land - subregion 2								+li										<	0
Water - subregion 2							+cw		-1	-1								<	0
Max fixed price water -- subregion 2									+1									<	Fpw
AUM grazing - subregion 2								+lg			-1	-1				-1		<	0
Max fixed price AUMs -- subregion 2											+1							<	Fpa
Labor -- FASOMGHG region	+clb	+alb					+clb	+alb						-1	-1			<	0
Max family labor -- FASOMGHG reg															+1			<	Fl
Primary Commodities -- FAS. region	-cy	-lny					-cy	-lny					+pp				+	<	0
Secondary Commodities -- FAS. regio		+ls						+ls					-ps				+	<	0
National inputs	+ci	+li					+ci	+li					+pi			-1	+	<	0

8.3.4.2.1 Irrigation water supply

In the irrigation water market, the fixed price component represents water available at a fixed price generally up to a maximum availability. That fixed price water depicts that made available largely through governmentally owned and distributed water that exists in the western US. The upward sloping supply curve component reflects the availability of privately traded surface and ground water where increasing use across that market causes increased pumping costs and water prices.

These variables are defined by agricultural region and make water available that is a available for any irrigation use in the region. They enter the objective function reflecting cost or the area underneath the supply curve. The fixed price water use also enters the row imposing maximum availability. GHG accounting associated with irrigation water pumping is not modeled in association with these variables, rather it is included in association with crop production.

8.3.4.2.2 AUM grazing supply

In the AUM grazing market, the fixed price component represents AUM grazing available at a fixed price generally up to a maximum availability. Such grazing represents that made available largely through grazing fees on governmentally owned lands in the western US. The upward sloping supply curve component reflects the availability of privately traded AUM grazing where increasing use increases AUM grazing rental rates.

These variables are defined by agricultural region and make AUM grazing available that is available for any AUM grazing use by livestock in the region. They enter the objective function reflecting the fixed per unit cost or the area underneath the supply curve. They also potentially enter the row imposing maximum availability.

8.3.5 Labor supply

In the labor market, the fixed price component is designed to represent family labor available at a fixed reservation wage below which the family will not work. This reservation wage is generally set at one half the prevailing hired labor rate. Family labor is assumed to be available at this reservation wage up to a maximum availability. The upward sloping supply curve component reflects the availability of hired labor where increasing use across the market leads to higher wages.

These variables are defined at the level of the 11 FASOMGHG market regions and make labor available across all subregions in each market region. That labor is assumed to be available for any and all production related agricultural labor use in the region.

The variables enter the objective function reflecting the reservation wage or the area underneath the hired labor supply curve. They also potentially enter the row imposing maximum availability.

8.3.5.1 Purchased input supply

Numerous inputs are made available at a fixed price. Potentially these could be subject to a maximum availability constraint but none are currently so constrained. These include fossil fuels, fertilizer, capital, sutom operations and a number of other categories as listed in the file in ***data_aginputname.gms***.

These variables are defined on a national basis in the units of dollars spent and make the input available for usage anywhere across the nation. They enter the objective function reflecting cost and are generally computed into objective function coefficients for the production activities. They also potentially enter a row imposing maximum availability. GHG accounting associated with fertilizer and fossil fuel use is modeled in association with crop and livestock production.

8.3.6 Commodity consumption and markets

An overview of the commodity market model structure is presented in table 8-21. That tableau portrays the sources of market supply and demand. These include

- Domestic supply from production
- Domestic interregional transportation
- International transportation
- Domestic demand
- Exports
- Imports
- Processing utilization and production

Commodities are sometimes subject to regional markets and are always subject to a national market. The tableau shows one case of each. For a commodity subject to a regional market, supply arises from production in subregions contained within that region, yields from processing and incoming transport from other regions as well as incoming transport from other countries (if the commodity is subject to a spatially explicit transportation trade representation).

Sources of regional demand include outgoing transport to other US regions, processing, outgoing transport to foreign countries (again if the spatially explicit trade modeling is present for the commodity) and transfer to the national market.

At the national market level for the regionalized commodities the supply is that transferred in from the regions. On the other hand for commodities without regional markets supply arises directly from the production variables. Under either case at the national level we see national demand, export demand and import supply as defined by excess supply and demand equations along with usage by national level processing. More about the explicit international trade model appears in the next section.

The equations in this tableau are:

- Welfare -- the consumers' and producers' surplus objective function that is maximized. In terms of the commodity market features, this incorporates the areas under the domestic and export demand functions less the areas under the import supply and foreign country supply curves. Transport costs are also sutracted. Many other terms like production and processing costs are also included. The GAMS implementation equation ***WELFAR*** is represented in this tableau row.
- Commodity balance -- Balances regionalized commodities in the US regions. These balances balance usage of commodities controlled on a regional basis (as listed above) with supply. Namely usage by processing, trade with other US regions, trade to other countries, direct use by production (not shown here but discussed in the livestock section above) and transfer to the national market does not exceed regional production, regional processing yield and incoming domestic/international transport. The constraint is defined at the FASOMGHG 11 region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Commodity balance -- National balances for regionalized commodities. These insure that consumption of commodities controlled on a regional basis (as listed above) balances against national demand. At the national level the source of supply is incoming movements from regions as well as imports when imports of this commodity are represented as if the total US faced a single excess supply equation for imports. National demand consists of domestic demand and export demand when exports are not spatially explicit. The constraint is defined for all of those commodities that are depicted on a regional basis. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Commodity balance -- Balances spatially explicitly traded commodities in foreign countries. These balances insure that usage of commodities subject to spatially explicit international trade modeling (as listed above) balance at the foreign country/region level.

Namely, demand from consumption in the foreign country, trade to US regions, trade to other foreign countries (not exquisitely shown here), is constrained so it does not exceed supply coming from the country excess supply equation, incoming shipments from the US and incoming shipments from other foreign countries. The constraint is defined for those commodities that are subject to spatially explicit trade modeling at the FASOMGHG 27 foreign country/region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.

- Commodity balance -- National balance for national commodities. These balances insure that usage of commodities controlled on a national basis (as listed above) balance against demand. The source of supply is regional production and processing yields, plus possible imports from the total US faced excess supply equation for imports. National demand consists of domestic demand, use of inputs by processing and export demand from an explicit rest of world excess demand equation. The constraint is defined for all commodities depicted on a national basis. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.

The variables depicted in this tableau are

- Production -- All crop and livestock production. These variables produce and possibly use commodities while incurring costs in the objective function. The commodities produced are either placed in the regional or national balances depending upon whether or not the commodity market is regionalized. The individual components are discussed in crop and livestock sections above.
- Transport of commodity to other US regions -- Flow of commodities between US regions. These are only defined for commodities subject to regional market modeling. These variables have a per unit transport cost in the objective function and reflect commodity usage from the region of origin plusa supply into the region of destination. Movement is modeled between the 11 FASOMGHG regions for each regionalized commodity. Cases within the GAMS implementation variable ***AGTRADE*** are depicted by this tableau column.
- Transport of regional commodities to and from foreign countries -- Flow of commodities between US regions and foreign countries/regions. They are only defined for commodities that are subject to spatially explicit international trade modeling. These variables have per unit transport cost in the objective function and reflect a usage of the commodity in the US or foreign region where the shipment originates plus a supply into the destination region. This international trade is modeled between the 11 FASOMGHG regions and 27 foreign countries/regions. Cases within the GAMS implementation variable ***AGTRADE*** are depicted by this tableau column.
- Regional processing -- Regional processing amounts across the 11 FASOMGHG regions. These variables have per unit processing costs in the objective function and reflect usage

of primary/secondary commodities as well as a supply of secondary commodities into the regional or national balances depending on the regionalization of the subject commodities. Cases within the GAMS implementation variable ***AGREGPROCESS*** are defined by this tableau column

- Regional commodity to national market -- Movement of commodities from the 11 FASOMGHG regions to the national market. These variables have an objective function coefficient that equals per unit observed regional to national price differentials.They reflect withdrawal from the regional commodity balance and addition into the national balance. These variables are defined for movements from the 11 FASOMGHG regions for the regionalized commodities. Cases within the GAMS implementation variable ***AGTRANSPRIM*** are defined by this tableau column
- Domestic demand -- Demand for national and regionalized commodities. National market demand for all commodities whether they be regionalized or nationalized. These variables have the area underneath the demand curve in the objective function and reflect usage of primary/secondary commodities from the national balance. These variables are defined for all commodities with domestic demand curves. Cases within the GAMS implementation variable ***AGDEMAND*** are defined by this tableau column
- Export demand -- Exports of commodities without explicit spatial trade modeling. Export market demand for all commodities that are modeled such that the US faces an aggregate rest of world excess demand equation. These variables have the area underneath the rest of world excess demand curve in the objective function and reflect usage of commodities from the US national balance. These variables are defined all the commodities for which explicit excess demand curves are defined. Cases within the GAMS implementation variable ***AGDEMAND*** are defined by this tableau column.
- Import supply -- Imports of commodities without explicit spatial trade modeling. Import market supply for all commodities that are modeled such that the US faces an aggregate rest of world excess supply equation. These variables subtract the area underneath the rest of world excess supply curve in the objective function and reflect supply of primary/secondary commodities into the national balance. These variables are defined all the commodities for which explicit excess supply curves are defined. Cases within the GAMS implementation variable ***AGSUPPLY*** are defined by this tableau column
- Processing -- Levels of processing for alternatives defined on a national basis. These variables have per unit processing costs in the objective function and reflect usage of primary/secondary commodities as well as supply of secondary commodities into the national balances. These variables are defined for the relevant processing alternatives. Cases within the GAMS implementation variable ***AGPROCESS*** are defined by this tableau column.

- Foreign country demand -- Foreign country level demand for commodities with explicit spatial trade. These variables have the area underneath the country level excess demand curve in the objective function and reflect use of commodities from the country level balance. These variables are defined all the commodities subject to spatially explicit international trade modeling for the countries with excess demand curves. Cases within the GAMS implementation variable ***AGDEMAND*** are defined by this tableau column
- Foreign country supply -- Foreign country level supply for commodities with explicit spatial trade. These variables subtract the area underneath the country level excess supply curve in the objective function and reflect supply of thes commodities into the country level balance. These variables are defined all the commodities subject to spatially explicit international trade modeling for the countries with excess supply curves. Cases within the GAMS implementation variable ***AGSUPPLY*** are defined by this tableau column

The coefficients in these equations are

c -- per unit cost of production
tc -- per unit costs of domestic interregional transportation
ti -- per unit cost of international transportation from US regions to foreign regions
pc -- per unit processing costs
pd -- per unit price differences between the prices in US regions and the US national price
di - the area underneath the national domestic demand curve
ei -- the area underneath the explicit rest of world export demand curve
Ii -- the area underneath the explicit rest of world import supply
xi - the area underneath the country specific excess demand curve
si -- the area underneath the country specific excess supply curve
y -- production of commodities
+/- -- a symbol representing use and creation of commodities by processing

Several characteristics merit discussion

- Only selected commodities are modeled with regional markets, all are modeled with national markets. Only commodities subject to spatially explicit trade, livestock feeds and biofuel feedstocks are regionalized as listed above table 8-4 through 8-6. The rest of the commodities are nationalized.
- Not all commodities are subject to national demand some are just produced and used as intermediate products.
- More details on the spatially explicit international trade modeling appear in the next section.
- Not all commodities are subject to international trade. Some are just limited to US exports but are not treated as commodities that can be imported when imports have not recently been observed. Others are subject only to imports but are not allowed to be

exported where US exports have not recently been observed. Yet others are only intermediate commodities are not traded at all.

Table 8-21 Tableau illustrating commodity markets

	Production regional commodity -- region 1	Production national commodity -- region 1	Transport regional commodity to region 2	Transport t regional commodity o countries	Transport regional commodity from countries	Processing -- region 1	Regional commodity to national market	Production regional commodity -- region 2	Production national commodity -- region 2	Transport regional commodity to region 1	Transport t regional commodity o countries	Transport f regional commodity from countries	Processing -- region 2	Regional commodity to national market	National demand for regional commodity	National demand for national commodity	National processing	National exports	National imports	Foreign country demand	Foreign country supply	
Welfare	-c	-c	-tc	-ti	-ti	-pc	-pd	-c	-c	-tc	-ti	-ti	-pc	-pd	+di	+di	-pc	+ei	-ii	+xi	-si	
Regional Commodity -- reg 1	-y		+1	+1	-1	+/-r	+1			-1												< 0
Regional Commodity -- reg 2			-1					-y		+1	+1	-1	+/-r	+1								< 0
Reg Commodity – foreign country				-1	+1						-1	+1								+1	-1	< 0
Reg commodity National balance							-1							-1	+1		+/-					< 0
National commodity balance		-y				+/-n			-y				+/-n			+1	+/-	+1	-1			< 0

8.3.7 Spatial international trade and interaction with domestic regions

Some commodities are modeled with spatially explicit international trade. Specifically spatial equilibrium submodels ala Takayama and Judge are incorporated for eight commodities -- hard red winter wheat, hard red spring wheat, durham wheat, soft white winter wheat, corn, sorghum, rice, and soybeans. These spatial equailibrium submodels depict movement of the subject commodities between the 11 FASOMGHG market regions and the 27 foreign countries/regions as named in table 3-7. Across these foreign countries/regions we have supply and demand curves for these commodities. Naturally not all regions are both suppliers and demanders. The tableau in Table 8-22 overviews the FASOMGHG spatial trade submodel features as they interact with the domestic market regions.

The equations in this tableau are

- Welfare -- The consumers' and producers' surplus objective function that is maximized. In terms of the spatial commodity market features, this function incorporates some purely domestic terms including the costs for domestic production, domestic interregional transport and movements from regions to the domestic national market along with the area underneath the domestic demand curves. The objective function also includes international terms accounting for transport cost from domestic to the international markets, the area underneath the international supply curves, the costs of moving from international regions to US regions, the costs of moving from international regions to other international regions and the area underneath the international demand curves. Domestic GHG payments are also included. The GAMS implementation equation ***WELFAR*** is represented in this tableau row.
- Commodity balance- US regional -- Balances usage of commodities with supply on a US regional basis. Namely, as discussed above, usage through trade with other US regions, consumption in national markets, and exports to other countries, along with domestic usage through processing and feeding (not shown here but discussed in the livestock and processing sections above) does not exceed supply. Supply arises from regional production, incoming domestic interregional transport and incoming international transport. The constraint is defined for those commodities that are depicted with spatially explicit trade characteristics at the FASOMGHG 11 region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Commodity balance- National -- Balances usage of against demand at the national level. At the national level the source of supply is incoming movements from the regions. The constraint is defined for all commodities that are subject to regional modeling including

all spatially traded ones. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.

- Commodity balance- Foreign countries -- Insures that commodities balance at the foreign country/region level. Demand from consumption in the foreign country, trade to US regions, plus trade to other foreign countries is constrained so it does not exceed supply coming from foreign country/region level supply curves, incoming shipments from US regions and incoming shipments from other foreign countries. The constraint is defined for those commodities that are subject to spatially explicit trade modeling at the FASOMGHG 27 foreign country/region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- GHG balance -- Balances GHG payments with net emissions. The most notable thing about this constraint in the context of spatially explicit trade is the absence of any entries in association with the international supply and demand. FASOMGHG only models domestic GHG accounts. Cases within the ***GHGACCOUNTS*** GAMS implementation equations are represented by this tableau row.

The variables depicted in this tableau are

- Production -- Aggregate crop and livestock production. This component is extensively discussed in the crop and livestock submodel sections above. These variables produce commodities while incurring costs in the objective function. The commodities produced that are subject to this spatially explicit trade modeling are always placed in regional balances.
- Transport of commodity to other US regions -- Flow of commodities between US regions. These variables incur transport cost in the objective function and reflect commodity usage in the region where the shipment originates plus supply into the destination region. Movement is modeled between the 11 FASOMGHG regions. Cases within the implementation variable ***AGTRADE*** are depicted by this tableau column.
- Transport of commodities from US regions to foreign countries -- Flow of commodities from US regions into importing foreign countries/regions. These variables incur transport cost in the objective function and reflect usage in the originating US region then supply into the destination foreign country/region. Trade is modeled between the 11 FASOMGHG regions and 27 foreign countries/regions where the US exports that commodity and the foreign country demands that commodity. Cases within the GAMS implementation variable ***AGTRADE*** are depicted by this tableau column.
- Regional commodity to national market -- Movement of commodities from the 11 FASOMGHG regions to the US national market as discussed above. Cases within the GAMS implementation variable ***AGTRANSPRIM*** are defined by this tableau column

- Domestic demand -- National market demand as discussed above. Cases within the GAMS implementation variable ***AGDEMAND*** are defined by this tableau column.
- Foreign country supply -- Country level excess supply for all commodities that are modeled with spatially explicit international trade. These variables have the area underneath the country level excess supply curve in the objective function and reflect supply of commodities into the country level balance. These variables are defined all the commodities subject to spatially explicit international trade modeling for the countries with excess supply curves. Cases within the GAMS implementation variable ***AGSUPPLY*** are defined by this tableau column
- Transport of commodities to US regions from foreign countries -- Flow of commodities into US regions from exporting foreign countries/regions. These variables incur per unit transport cost in the objective function and reflect a usage of the commodity in the originating foreign country/region plus supply into the US destination region. Trade is modeled between the 11 FASOMGHG regions and 27 foreign countries/regions for each commodity for cases where the US imports that commodity and the foreign country supplies that commodity. Cases within the GAMS implementation variable ***AGTRADE*** are depicted by this tableau column.
- Transport of commodities between foreign countries -- Flow of commodities between foreign countries/regions. These variables incur transport cost in the objective function and reflect usage in the originating foreign countrys plus supply into the destination region. This international trade is modeled between pairs of the 27 foreign countries/regions when transport costs are defined and when a country of origin is a supplier and the country of destination is a demander. Cases within the GAMS implementation variable ***AGTRADE*** are depicted by this tableau column.
- Foreign country demand -- spatially traded commodities -- Country level excess demand. These variables have the area underneath the country level excess demand curve in the objective function and reflect use of the commoditiy from the country level balance. These variables are defined for the countries with excess demand curves. Cases within the GAMS implementation variable ***AGDEMAND*** are defined by this tableau column.
- GHG Payment -- Net GHG payments in the model as has been discussed above. Cases within the ***AMOUNTGHGS*** GAMS implementation variables are represented by this tableau column.

The coefficients in this tableau are

c -- the costs of crop production
dt -- the cost of domestic interregional transport
pd -- domestic price differences between regional and national markets
i -- the area underneath the domestic demand curve
it -- transport cost for moving goods from domestic to international regions or vice versa

is -- the area underneath the foreign country supply curve
ic -- transport cost for moving goods between international regions
id -- the area underneath the foreign country/region demand curves
g -- GHG payments
y -- production yields
+/- -- a portrayal of coefficients of various sign in the GHG balance

Several features of this spatially explicit trade model merit mention

- As mentioned above the spatially explicit trade modeling is only done for select commodities in the model.
- Trade for other commodities generally is represented with excess supply and demand functions that face the total US on a rest of world basis as is discussed in the section on commodity markets above.
- Not all US regions are involved with the export and/or import of each commodity. Shipments to foreign countries only occur where they have been observed in the past. In particular, landlocked US regions generally transport commodities to regions with ports who in turn export to the foreign countries/regions. For example exports to Asia are more likely to come from the West Coast and do not originate directly from the Corn Belt.
- Not all foreign regions are suppliers or demanders of a commodity. Generally the foreign regions are a supplier, a demander or neither. Some regions simply do not produce particular commodities, are self-sufficient or are not significantly involved in international trade.
- Most of the data behind this model for the elasticities used in the supply and demand equations are based on the USDA SWOPSIM model. Transport data comes from some efforts by Dr. Stephen Fuller and associates at Texas A&M. Data on quantities and prices come from a mixture of USDA, World Bank and FAO sources.

Table 8-22 Tableau illustrating spatially explicit trade and relation to domestic regions

	Production region 1	Production region 2	Domestic transport region 1 to region 2	Domestic transport region 2 to region 1	Move from region 1 to US National market	Move from region 2 to US National market	US national market	International transport from US region 1 to country 2	International transport from US region 2 to country 2	International supply country 1	International transport from country 1 to US region 1	International transport from country 1 to US region 2	International transport from country 1 to country 2	International Demand in country 2	GHG payments	
Welfare	-c	-c	-dt	-dt	-pd	-pd	+i	-it	-it	-is	-it	-it	-ic	+id	+g	
Commodity balance -- US region 1	-y		+1	-1	+1			+1			-1					< 0
Commodity balance -- US region 2		-y	-1	+1		+1			+1			-1				< 0
Commodity balance -- US national					-1	-1	+1									< 0
Commodity balance -- country 1										-1	+1	+1	+1			< 0
Commodity balance -- country 2								-1	-1				-1	_1		< 0
GHG fossil emissions	+/-	+/-													+1	= 0

8.3.8 Biofuels

One of the key potential GHG mitigation strategies involves offsetting fossil fuel based carbon emissions by providing biofuels feedstocks that after conversion can prodiide proucts that replace gasoline, diesel and/or coal for electric power plants. Table 8-23 shows a tableau that overviews the biofuel submodel.

The equations in this tableau are

- Welfare -- the consumers' and producers' surplus objective function that is maximized. In terms of the biofuel feedstock features, this incorporates the cost of feedstock production whether it involves traditional crops like corn or specialized energy crops like willow, hybrid poplar, or switchgrass. The costs of processing in and commodity movement from the forest sector also appear. The objective function also includes the costs of utilizing biofuel feedstocks that integrate hauling and transformation costs to a point at which the resultant product is perfectly substitutable with the fossil energy source. These costs occur in association with processing variables. Finally, the objective function incorporates demand coefficients that reflect the prices received when generating ethanol and biofuel feedstocks for electricity generation. In these cases, the demand curves are currently assumed to be infinitely elastic at a fixed price but could be specified as downward sloping in the future. The GAMS implementation equation ***WELFAR*** is represented in this tableau row.

- Commodity balance of raw commodities -- Balances usage of biofuel feedstock commodities with their supplies. Namely, usage by processing, transfer to forestry as a fiber source, other direct use by production plus other forms of demand/production/processing/export (which really only occurs for corn) does not exceed regional production, plus transfers from forest processing. The constraint is defined for all of the biofuel feedstock commodities at the FASOMGHG 11 region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Commodity balance of processed agricultural commodities -- Balances usage of byproducts that can be utilized as biofuel feedstocks with supply of those byproducts. Namely usage by processing of cornstarch, corn oil and soybean oil does not exceed regional processing yields. The constraint is defined at the FASOMGHG 11 region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Commodity balance of energy replacements -- Balances usage of ethanol, biodiesel and power plant feedstocks with supply of those products arising directly through raw product production, transfer from forest processing and yields from agricultural processing. The constraint is defined at the FASOMGHG 11 region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Commodity balance of other commodities -- Balances usage of byproducts generated during the biofuel production process with supply of those byproducts. Namely usage of byproducts like brewers grain (that is produced during the wet milling process from which the cornstarch is produced and in turn used in ethanol production) does not exceed regional processing yield. The constraint is defined at the FASOMGHG 11 region level. Cases within the ***AGPRODBAL*** GAMS implementation equations are represented by this tableau row.
- Wood products -- Balances usage of logs and milling residues in the forestry sector with quantities available. This constraint is a marker for the broader forestry submodel as extensively discussed in above forestry model section.
- Maximum energy penetration limits -- Limits maximum market penetration of fossil fuel replacements. More explanation regarding these constraints appears after the definition of the coefficients below. These equations are defined at the national level for ethanol and at the FASOMGHG 11 region level for biofuel power plants. They are imposed either as upper bounds on the ***AGDEMAND*** GAMS implementation variable and/or through limits

on the usage of inputs within the ***AGPROCESSMAXPURCHINPUT*** GAMS implementation equation.

- GHG balance of fossil and non-CO2 emissions -- Balances GHG emissions generated through the feedstock production use of fossil fuel, fertilizer and other inputs with net payments therefore. In the biofuel feedstock context this involves accounting for the emissions from fossil fuel, fertilizer, etc. used during biofuel feedstock production plus any energy used in transport and processing. Cases within the GAMS implementation equation ***GHGACCOUNTS*** are depicted by this tableau row.
- GHG balance of energy offsets, carbon and non-CO2 -- Net GHG emissions savings generated through the replacement of combustion of fossil fuel by biofuel feedstocks. This will be discussed following the definition of the coefficients below. Cases within the GAMS implementation equation ***GHGACCOUNTS*** are depicted by this tableau row.

The variables depicted in this tableau are

- Biofuel feedstock production -- Acres devoted to biofuel feedstock production. These variables produce commodities while incurring costs in the objective function and generate GHG emissions due to the use of fossil fuel, fertilizer and other agricultural inputs. Sequestration is also present as described in the crop submodel section above. As discussed in the crop section above they also use crop land, tilled land, irrigation water and labor. The biofuel feedstock commodities produced are placed in regional balances. These variables are defined by crop, region, fertilizer use, tillage practice, crop land type, and irrigation status. Cases within the ***AGCROPBUDGET*** GAMS implementation variables are represented by this tableau column.
- Forest processing -- Processes in the forest sector that generate logs and/or milling residues that can be used as biofuel feedstocks. More on these features are covered in the forestry chapter above.
- Agricultural processing -- Biofuel feedstock generation. Processing activities that generate secondary commodities that can be used as biofuel feedstocks. These include corn wet milling and soybean crushing. These variables use raw commodities and agricultural inputs while generating a secondary commodity that can be used as a biofuel feedstock like corn starch along with other commodities like brewers grain. They also utilize agricultural inputs and generate fossil fuel related GHG emissions. These variables are defined on a FASOMGHG 11 region. Cases within the ***AGREGPROCESS*** variables are represented by this tableau column.
- Agricultural processing that generates ethanol. Several processing activities generate ethanol from biofuel feedstocks. These include conversion of cornstarch into ethanol along with cellulosic ethanol generation from switchgrass, hybrid poplar and willow. These variables use raw commodities or cornstarch along with agricultural inputs while

generating ethanol. They also generate fossil fuel related GHG emissions and generate gasoline replacement based GHG offsets. These variables are defined on a FASOMGHG 11 region basis. Cases within the ***AGREGPROCESS*** variables are represented by this tableau column.

- Agricultural processing that generates coal replacements for use in electricity generation. Processing activities that generate biofuel feedstocks capable of substituting for coal within electricity generation. These include use of energy crops and products from the forest sector and all the costs of the transforming them to the point that they are substitutes on a BTU heat unit basis for coal as an input to a power plant. These variables use raw biofuel feedstocks or forest commodities along with agricultural inputs reflecting hauling and other costs while generating BTUs of replacement feedstock. They also generate fossil fuel related GHG emissions and generate coal usage based GHG offsets. These variables are defined on a FASOMGHG 11 region basis for the relevant types of processing alternatives. Cases within the ***AGREGPROCESS*** variables are represented by this tableau column.
- Demand for ethanol in gasoline blends -- Demand for agriculturally based ethanol blended into a liquid fuel mix that is or is not subject to the full extent of fuel taxes as a potential implicit subsidy. The unsubsidized possibility is included to raise the possibility of unsubsidized gasoline blends when large expansions in ethanol production are realized. The variable has an objective function coefficient that reflects a fixed price, and withdraws ethanol from the processed commodity balance row. The subsidized alternative is subject to an upper bound set at the current level of subsidized ethanol production. The variable is defined on a national basis over time for each of the two ethanol subsidy possibilities. Cases within the GAMS implementation variable ***AGDEMAND*** are represented by this tableau column.
- Demand for electricity feedstock in tbtus -- Demand for agriculturally based feedstocks to power plants in trillion btus. The variable has an objective function coefficient that reflects the area underneath a fixed price demand curve, withdraws the feedstock in thermal units (trillion BTUs) from a commodity balance row. The variable is defined on a national basis over time. Cases within the GAMS implementation variable ***AGDEMAND*** are represented by this tableau column.
- GHG payments/taxes -- Net GHG payments as has been discussed above. Cases within the ***AMOUNTGHGS*** GAMS implementation variables are represented by this tableau column.

The coefficients in these equations are

c -- per unit cost of agricultural production
pr -- per unit cost of forestry processing

r -- per unit cost of agricultural processes that make biofuel feedstocks into replacements for fossil fuels
i -- per unit prices for commodities that replace fossil fuels
y -- per unit yield of biofuel feedstock
u -- per unit usage of raw commodities in processing
p -- per unit yield of secondary biofuel feedstocks or energy commodity replacements
Eth -- maximum quantity of subsidized ethanol that can be sold
Elec -- maximum quantity of biofuel feedstock coal replacement that can penetrate the marketplace over time
ce -- carbon emissions from crop production
pe -- carbon emissions from agricultural processing
co -- carbon offsets generated when making biofuel feedstock based replacements for coal in electricity generation
go -- carbon offsets generated when making biofuel feedstock based replacements for gasoline
ne -- non-CO2 emissions from crop production
pn -- non-CO2 emissions from agricultural processing
gn -- non-CO2 offsets generated when making biofuel feedstock based replacements for coal in electricity generation
no -- non-CO2 offsets generated when making biofuel feedstock based replacements for gasoline

Several features of the biofuel model merit discussion.

- The biofuels feedstocks model is resident within the agricultural sector and as a consequence is an annual representation of activity that will be constant across a five year period.
- The commodities involve include forestry and agricultural commodities.
- The possible rate of substitution for energy commodities is subject to market penetration constraints. Two forms of such constraints are defined.
    - The ethanol one is included to preclude the possibility of a ten or more fold increase in ethanol production that by default is subject to the degree of implicit subsidization that is present within current policy in the form of gasoline tax forgiveness. This obviously is a policy decision. This maximum is specified in the ***commodsupdem*** table for the commodity ***SubGasBlend*** in the file ***data_agsupdem.gms***.
    - Market penetration constraints that limit the amount of biofuel feedstock that can be used in generating electricity. The motivation for this constraint is that biofuel feedstocks can only be used in electricity generation if (a) new plants are constructed with biofuel capabilities which this depends on the rates of (1) demand growth and (2) existing plant depreciation; or (b) the retrofit of existing plants so they can use biofuel feedstocks. Such processes all take time and require substantial investments. Forecasted projections of electricity market biofeedstock penetration rates were taken

from the Haq's work at the Energy Information Agency and are present in the ***BioMktPenReg*** table in the file ***data_agbiomass.gms***.

- The net effect on GHG net emissions from biofuel feedstock usage involves the offset of the emissions from replaced fossil fuel that would have been combusted less the costs of the emissions incurred in biofuel feedstock production and processing.
- Biofuel feedstock offsets not only affect carbon, but also methane and nitrous oxide based on lifecycle accounting results found in the literature. The data on these emissions offsets are present in the ***regionalprocess*** table in the ***data_agprocessregional.gms*** file for the biofuel feedstock related processing alternatives.
- The coefficients giving the amount of emissions offset when biofuel feedstocks replace fossil fuel are based on the fact that when growing the feedstocks absorb atmospheric carbon dioxide through photosynthetic processes and store them in the body of the feedstock in the form of carbon. In turn, when that feedstock or derivative products thereof are combusted as energy substitutes then the absorbed carbon is reemitted to the atmosphere. However, the net gowing and processing energy is often substantially less than the magnitude of the fossil fuel combustion emissions. As consequence the emissions from combustion can be either zero or greatly reduced as these emissions are offset by the photosynthetic absorption. The data on these emissions offsets are present in the ***regionalprocess*** table in the ***data_agprocessregional.gms*** file for the biofuel feedstock related processing alternatives.

Table 8-23 Tableau illustrating biofuels production

	Production corn	Production energy crop	Forest processing	Wet mill corn	Process corn into ethanol	Process energy crop into ethanol	Process energy crop into electricity	Process forest residues and chips to elec	Demand subsidized ethanol in gas	Demand for unsubsidized ethanol in gas	Demand for electricity in tbtus	GHG payments		
Welfare	-c	-c	-pr	-r	-r	-r	-r	-r	+i	+i	+i	+		
Commodity balance - corn	-y			1									≤	0
Commodity balance -- energy crops		-y				+u	+u						≤	0
Commodity balance -- corn starch				-p	+uu								≤	0
Commodity balance -- brewers grain				-p									≤	0
Commodity balance -- ethanol					-p	-p			1	1			≤	0
Commodity balance -- electricity							-p	-p					≤	0
Wood products			+										≤	0
Forest milling residues and chips			-y					+u					≤	0
Max subsidized ethanol									1				≤	Eth
Max electricity penetration							+1	+1					≤	Elec
GHG fossil emissions	ce	ce		pe	pe	pe	pe	Pe				-1	=	0
GHG coal offset							co	Co				-1	=	0
GHG gasoline offset					go	go						-1	=	0
GHG non co2 emissions	ne	ne		pn	pn	pn	pn	Pn				-1	=	0
GHG non co2 offset					gn	gn	no	No				-1	=	0

8.3.9 Time

Operating the agricultural submodel in conjunction with the forestry submodel raises a number of dynamic issues. These are discussed in this section. In particular, since the forestry model spans many years and the agricultural model is a shorter-term equilibrium model, then there are issues of coordinating the two submodels, equating welfare across them, updating agricultural activity over time and ltreating and valuation in the terminal period.

8.3.9.1 Coordinating the agriculture and forestry submodels

The forestry sector submodel is a multi-period model such that when a forest stand is established it may be 30 to 50 years before that stand is harvested. On the other hand, the agriculture model depicts cropping and livestock activity in a typical equilibrium year assuming that the same activity persists over a five year time period. The dynamics of any perennial crop or livestock possibilities (excepting the sequestration implications of tillage and land use change) are assumed to be able to worked out in each typical five year period. The general way this works is summarized in the discussion surrounding the chapter 9 table 9-1.

8.3.9.2 Discounting and annuities

The agricultural model is assumed to represent typical activity during each year of a five year period (running from year 0 to year 4). Thus, agricultural returns in each period excepting the last one were treated as if they were a continuing annual series of five equal amounts discounted to the first period's dollars. In the last period the returns were treated as if they were an infinite annuity as will be discussed in the next section. Thus the period specific annuity factor d_p

$$d_p = \sum_{t=0}^{4} \frac{1}{(1+r)^t} \quad \text{for} \quad 1 \le p < P$$

and

$$d_p = \frac{1}{r} \quad \text{for} \quad p = P$$

where

r is the discount rate for period p as defined in the GAMS parameter ***discrate*** in ***data_basicsets.gms*** as is typically reset in the file ***model_structure.gms***

P is the last time period as is defined in the set called ***period*** in ***data_basicsets.gms*** and may be reset in ***model_structure.gms***.

In turn the agricultural part of the objective function is

$$W = \sum_{p=0}^{5} \frac{1}{(1+r)^{5p}} d_p \, AgWel_p$$

where

W is the net present value of agricultural welfare

d_p is the period specific annuity factor which is contained in the model in the array ***Annuitywt(periods,"agriculture")*** as computed at the top of the ***model_structure.gms*** file

p identifies the five year time period

$AgWel_p$ represents the multi term agricultural consumers' and producers' surplus objective function in multi year time period p

- The term involving (1+r) exponentiated to the 5p provides a discount factor to take the net present value of the returns in each time period back to the first model period.

- Multiplying by period specific annuity factor d_p converts the returns in each five year period to net present value in the dollars of the first year in each period.
- All of this is implemented in the ***WELFAR*** equation within the file ***model_structure.gms***

8.3.9.3 *Terminal period agricultural land use valuation*

While the model structure readily treats net returns from the uses of agricultural lands along with the net returns to existing and regenerated forest stands during the explicit FASOMGHG periods, additional provisions are required to accommodate net returns beyond the end of the projection period.

Because land values in any use reflect the present value of an infinite stream of future net returns, it is theoretically inappropriate to ignore land values at the end of our finite projection period. In practical terms, some rotation ages in the forest sector can be as long as 90 years and omission of terminal conditions or terminal land values could lead the model to fail to replant after initial harvest, perhaps as soon as the third decade in the solution. In turn, adding valuation of such existing stands in terms of their future returns beyond the explicit model time periods requires that one also value agricultural land in continuing agricultural use beyond the explicit model time periods. If this is not done the model would simply transform agriculture lands into forestry to capture net returns beyond the explicit model time horizon.

Terminal conditions in forestry are handled as constant perpetual using von Mantel's formula as discussed in chapter 7. In the agricultural sector, activity in the last period is treated as if it continues forever. This is done using the mathematical relation that

$$\sum_{t=0}^{\infty}\frac{1}{(1+r)^t} = \frac{1}{r}$$

which explains why this is the annuity factor used in the final explicit model period.

8.3.9.4 *Updating yields, demand levels and other factors over time*

Features have been added to FASOMGHG to reflect market and production condition changes over time. In the agricultural sector submodel, there are exogenously specified growth rates in yields, domestic demand, imports and exports for the major commodities. Also rates of change are specified for the quantities available of and prices for crop land, pasture, AUMS, labor, and water as well as the prices of inputs. Finally, there are features that update the usage of inputs when yields change within the crop and livestock budgets.

The basic mechanism for updating falls into two classes. There are items that are updated based on time and those updated based on yield changes. The time-updated items include yield levels, demand, import levels, and supplies and quantities of available inputs. In all cases, these are updated by a formula $(1+ r_i)^t$ where r_i is the annual rate of change for item i. The r_i terms have been estimated by either using 40 years of agricultural statistics to determine the annual percentage rate at which those items have increased over time, or by computing rates from the USDA Economic Research Service's Agricultural Outlook projections (1990-2002). The data specifying the rates of change appear in the file ***data_agdynamic.gms***.

The model then takes the base quantities and the elapsed time to the future year for which desired data are needed and multiplies the base quantity by $(1+ r_i)^{t\text{-}base}$ to update yields, demand quantities, etc. in the file ***data_agdynamic.gms***. It is important to observe that both yields and demand are being updated. It is also important to be careful in balancing rates of growth in demand across uses. For example, one might want to change the rate of growth in corn disappearance. To do this, one needs to consider export demand, domestic demand, and feeding dimensions, all of which are treated in various functions.

The other major updating feature involves input adjustments related to yield levels. Such updating is done for crop input uses, crop profits, livestock feed use, and livestock profits. The procedure used here employs an elasticity term that gives the percentage response of input usage to a percentage change in yield. Input usage is changed by the percentage change in yield times that elasticity. Elasticities are based on three different assumptions. First, based on results derived by Robert Evenson (xxx cite), the elasticities for inputs for which we have no data are set at 0.5. This includes crop and livestock profits, as well as, in some cases, other crop inputs. Second, the elasticity of input change with respect to crops has been derived from a 1five year period from the mid 70's to the early 90's based on USDA FEDS budgets. During this period, the percentage change in input usage per percent change in yields is explicitly calculated and then used in specifying the elasticity. When such data are not available, 0.5 is used. Third, livestock feed use is assumed to be directly proportional to yield increases. Thus, if there is a 10% increase in milk output, there is a 10% increase in assumed feed consumption. All of this is done in the file ***data_agdynamic.gms***

The overall updating procedure, then, is to use the rate of change data to project all the demand, yield, import, and export figures for each of the FASOMGHG five year time periods and is implemented in the file ***data_agdynamic.gms***. Subsequently, based on the yields, input uses in the production budgets are updated using the elasticity of input use change with respect to yield change times the projected yield change and this is implemented in ***model_structure.gms***.

8.3.10 Varying regional granularity over time

FASOMGHG can be quite large. As a consequence, the agricultural submodel is designed so that it can operate with varying degrees of geographic aggregation across the different modeled time periods. In particular, the 63 subregion representation can be used at the beginning and then reduced to an 11 region representation. This is controlled by the ***yessub*** GAMS parameter which

- when set to one brings in the 63 subregion representation and
- when set to zero causes FASOMGHG to operate continually at the 11 region level.

When ***yessub*** is set to one the GAMS array ***yesdis(period)*** defines the time periods for which agricultural subregions will be used. Both of these items are defined at the beginning of the ***model_structure.gms*** file. Currently, the empirical set up causes the disaggregate subregions to be used in the first 20 years.

This strategy is employed to deliver detailed solutions at the beginning of the time frame while making computer solutions faster and reflecting the future consequences of early decisions. In terms of model structure, this involves aggregating the future consequences of any subregional decisions that influence resource availability or use into the corresponding FASOMGHG 11 regions. This is illustrated in the tableau in table 8-24. There we illustrate the altered regional granularity in a two period setting where in the early time period we have 4 subregions and in a later time period we have 2 aggregate regions where subregions 1 and 2 fall into region A while subregions 3 and 4 fall into region B.

The equations in this tableau are

- Pasture Land -- Limits the pasture land use to that available. The availability is the initial amount of agricultural pasture land adjusted for land use change. Only the transformation case to crop land is shown here, but in the full FASOMGHG equations, there would also be transformations to and from forest land plus a crop land to pasture case. This land is used by the livestock production variables. Initially the pasture land use limits are defined on a subregional basis as shown in time period 1. However later its regional basis so it limits land use on larger regional basis as shown in period 2. Cases within the ***AGPASTLANDEXCHANGE*** and ***AGLANDPASTURE*** GAMS implementation equations are represented by this tableau row.
- Crop land -- Limits crop land usage by tillage system to that available by crop land quality type. The land use is limited to the initial crop land endowment adjusted for land use change. Only the transformation case from pasture is shown here, but in the full

FASOMGHG there would be transformations to and from forest land plus a crop land to pasture case. Limits crop land use on a subregional basis when subregional basis when subregions are defined as shown in time period 1. However its regional basis is later altered so it limits land use on larger region basis as shown in period 2. Cases within the ***AGTILLSTART, AGTILLUSE*** and ***AGCANCHANGETILL*** GAMS implementation equations are represented by this tableau row.

The variables in this tableau are:

- Land from pasture -- Shifting of pasture land into crop land. These variables reflect the supply of land by geographic region from the single homogeneous pasture land equation into the land quality subcases in the crop land equations. The coefficients reflecting supply are proportional to their initial relative abundance of quality types in supply. These variables are defined geographically on the same basis as is agricultural production by time period. Thus in this illustration they are defined for subregions in the first period but only for the FASOMGHG 11 regions in the second period. Cases within the ***AGPASTLNDUSECHG*** GAMS implementation variables are represented by this tableau column.
- Crop prod. -- Amount of crop production undertaken as discussed above. This variable would have dimensions of region, crop, land type, tillage system, fertilization alternative, irrigation/dryland and time period. The ***AGCROPBUDGET*** GAMS implementation variables are represented by this tableau column. The ***AGINITIALTILL*** and ***AGCHANGETILL*** GAMS implementation variables would also be involved.

The coefficients in this tableau are

p -- Pasture usage per head of livestock production
L -- initial endowment of crop and pasture land
a1 -- proportional share of crop land in land quality class 1 in the initial land endowment data
a2 -- proportional share of crop land in land quality class 2 in the initial land endowment data

Several comments are in order regarding this representation

- The tableau only portrays the geographic granularity related procedures in terms of land use change from pasture to crop land. Similar procedures are used with transformation of land from and to other sources as well as with tillage change.
- Transformations from crop land to pasture are treated identically to the pasture to crop land case above but with all the signs flipped.

- Land transfers from forest to agriculture always come from a forest land inventory that is defined by the FASOMGHG 11 regions but can go into a 63 region agriculture. Consequently these must be meshed. When needed this is done by supplying land into the subregions in a manner proportional to the share of each subregion within the original agricultural land data by FASOMGHG region as discussed above or in chapter 9 below. In later time periods this land transfers on a one-to-one basis between the corresponding forest and agricultural regions. Naturally when moving to crop land the land coefficients are distributed proportionately to the incidence of the crop land quality types in the initial land endowment.
- Transformations from crop land to forest are treated identically to the forest to crop land case with all the signs flipped.
- Agricultural tillage transformations that occur in a particular subregion will supply and use the appropriate tilled land case in the appropriate more aggregate region in the later time periods.
- Crop and livestock budget data are aggregated into the larger regions using weighted acerages the 1992 crop and livestock mixes. Facotr suppliy prices are aggregated using endowment weighted averages.

Table 8-24 Tableau with varying regional granularity

	Transfer pasture to crop subregion 1 period 1	Transfer pasture to crop subregion 2 period 1	Transfer pasture to crop subregion 3 period 1	Transfer pasture to crop subregion 4 period 1	Produce livestock pd 1 subreg 1	Produce crops pd 1 subreg 1 land type 1	Produce crops pd 1 subreg 1 land type 1	Produce livestock pd 1 subreg 2	Produce crops pd 1 subreg 2 land type 1	Produce crops pd 1 subreg 2 land type 1	Produce livestock pd 1 subreg 3	Produce crops pd 1 subreg 3 land type 1	Produce livestock pd 1 subreg 4	Produce crops pd 1 subreg 4 land type 1	Transfer pasture to crop region A period 1	Transfer pasture to crop region B period 1	Produce livestock pd 1 region A	Produce crops pd 1 region A land type 1	Produce crops pd 1 region A land type 1	Produce livestock pd 1 region B	Produce crops pd 1 region B land type 1		
Pasture land subregion 1 in period 1	+1				+p																	<	L
Crop land subregion 1 type 1 in period 1	-a1					+1																<	L
Crop land subregion 1 type 2 in period 1	-a2						+1															<	L
Pasture land subregion 2 in period 1		+1						+p														<	L
Crop land subregion 2 type 1 in period 1		-a1							+1													<	L
Crop land subregion 2 type 2 in period 1		-a2								+1												<	L
Pasture land subregion 3 in period 1			+1								+p											<	L
Crop land subregion 3 type 1 in period 1			-a1									+1										<	L
Pasture land subregion 4 in period 1				+1									+p									<	L
Crop land subregion 4 type 1 in period 1				-a1										+1								<	L
Pasture land region A in period 2	+1	+1													+1		+p					<	L
Crop land region A type 1 in period 2	-a1	-a1													-a1			+1				<	L
Crop land region A type 2 in period 2	-a2	-a2													-a2				+1			<	L
Pasture land region B in period 2			+1	+1												+1				+p		<	L
Crop land region B type 1 in period 2			-a1	-a1												-a1					+1	<	L

8.3.11 Environmental accounts

A number of environmental accounts are computed mostly in association with crop land production. These include the amount of

- wind and water erosion
- fertilizer use
- pesticide use
- fertilizer run off

and a number of other items.

Most of these data come from EPIC crop simulator runs that were done at the level of crop production possibilities. The remaining data come from the crop production budgets. These environmental accounts will be added up in the report writer but are not formally incorporated within the FASOMGHG programming model.

9 CHAPTER 9 FOREST AND AGRICULTURE LINKAGES

The agricultural and forestry submodels are largely independent. However, commodity and land market linkages are present in FASOMGHG. These involve:

- intersectoral land transfers, and
- intersectoral commodity transfers.

When making such linkages, efforts are required to:

- synchronize different geographies, and
- synchronize time using discounting and annuities.

The model also reflects:

- Intersectoral tradeoffs under policies.

Each will be discussed in this chapter.

9.1 Intersectoral land transfers

Land can be used within either the agricultural or the forestry sectors. When a forested stand is clearcut, the resultant land now devoid of trees can be reforested, transferred to agriculture, or transferred to developed use. In addition, land now in agricultural production can be transferred into forest. Thus, in each time period, land balances are present in both the forestry and agricultural submodels and model variables depict the active decision whether to change land use from or to the other sector. Naturally, this also requires that the other sector be defined in the region at hand (this is not true for the PNWW, NP, and SW regions) and that land suitable for movement to the other sector exists (FORCROP, CROPFOR, CROPPAST or PASTFOR). The land use change decisions embody a number of modeling features and dynamic considerations as we discuss here.

The model is basically designed to consider whether the net present value of the future returns to land in the other sector outweigh those earned if land remains in the sector plus any adjustment costs involved with land transfers. If this is the case, then land will transfer and this rate of transfer will continue until the land markets equilibrate such that the value of the marginal acre in either sector differs by no more than the transfer costs. In forestry, this calculation considers the returns to reestablishing a stand plus the value of all future stands that would succeed the stand now being considered and the terminal value of any unharvested trees at model end. On the agricultural side, this considers the returns to land in cropping and/or livestock uses in the current plus all future periods including the final, perpetual one. In both cases land use changes may occur now or any time in the future and may include more than one change with for example agricultural land migrating to a forest use for a rotation then back to agriculture.

A tableau that reflects such decisions appears in table 9-1. There we see that multi-period forest variables that only enter the land markets in periods when a forest stand is being established or upon clearcut harvest. On the agricultural side, the agricultural submodel is an annual equilibrium model that repeatedly occurs in each of the five year periods. When land moves into the agricultural sector, the land transfer variables supply land into either

- crop land under conventional tillage in a dryland state or
- pasture land

from the period of transfer through the end of the explicit time period. The land is then used in period-specific agricultural variables. This multi-period supply is employed to reflect a land use decision that looks at current and future returns to land, along with performing the needed synchronization with the multiple submodels representing single period equilibrium agricultural production.

In this tableau, when land transfers sectors, we see that costs are encountered. On the forestry side, as discussed in Chapter 7, the costs of outgoing transfers face a three-step escalating cost schedule, where a given amount of land can transfer at an initial cost, but then as more and more land transfers the costs rise. The costs of this land transfer from forest to agriculture reflect the costs of stump clearing and other needed activities required to get the land ready for agricultural production. On the agricultural side, we have a specified hurdle cost of moving agricultural land to forestry plus establishment costs that are present in the production cost data in the forest submodel. These hurdle costs largely reflect a cost above and beyond the direct income difference that arises because one is moving from an annual income agricultural regime to a regime where returns are earned in the more distant future only after a lag for tree growth.

The equations in this tableau are

- *Welfare* -- Adds up total consumers' and producers' surplus across the two sectors and time periods using a net present value approach less any intersectoral adjustment costs. This tableau row represents the GAMS implementation equation ***WELFAR***.
- *Forest land* -- Balances land within the forest sector with its transfer and use. Land supply includes the land obtained from clearcut harvest plus land coming from agriculture. Land use includes its subsequent use for reforestation or land use change.

The land use changes allowed are movements to agriculture or movement to developed use. This equation is defined by log producing region (***logregions***), land suitability class (***class***), forest owner (***pvtlogowner***), type of succeeding forest stand (***sucessorgroup***), site index (***site***), and time period (***period***). The GAMS implementation equations ***FORLANDBALANCE*** and ***FORAFFORLANDBALANCE*** are represented by this tableau row.

- *Forest resources* -- Represents the production cost, non-wood input, and manufacturing capacity resources in the forest submodel as discussed in chapter 7.
- *Forest terminal valuation* -- Values standing forest inventory that exists beyond the explicit model time frame as discussed in chapter 7.
- *Agricultural land* -- Balances land supply within the agricultural sector with its use. Supply includes the land initially in agriculture plus land coming from forestry. Use within agriculture involves that for cropping or livestock. Other uses are the land use changes allowed as movements to forestry or movement to developed use. Adjustments are also made for land use change involving transfers between crop and pasture land. This equation is defined by agricultural region/subregion (***agregion***), land type including land quality (***aglandtype***), and time period (***period***) for conventional tillage when dealing with crop land. The GAMS implementation equations ***PASTLANDEXCHANGE*** and ***AGCANCHANGETILL*** are represented by this tableau row. The GAMS implementation equations ***AGLANDPASTURE, AGMAXPASTURETOCROP, AGTILLSTART,*** and ***AGTILLUSE*** are also involved**.**
- *Agricultural resources* -- Represents the water, AUMs, and labor agricultural submodel features as discussed in chapter 8.
- *GHG balance* -- the GHG balance as discussed above. In this case, it shows additions and subtractions for the GHG balance to account for land moving to and from the forest soil sequestration accounts.

The variables in this tableau are

- *Establish and harvest forest stand* -- Clearcuts of existing stands and establishment of forests on previously forested or agricultural land. Note the variables reflect an establishment and harvesting (clearcut) time period. Cases within the GAMS implementation variables ***FORPRDEXIST, FORPRDNEW, FORPRDNEWAFFOREST*** are represented by this tableau column. Also implicit are the remainder of the forest sector variables discussed in chapter 7 that involve cost, wood product manufacturing, trade, domestic consumption, and transport.
- *Forest terminal inventory* -- Valuation of terminal inventory that reflects the net present value of stands carried beyond the explicit model time period. This is discussed in chapter 7.
- *Ag production* -- Agricultural land use by crop and livestock production. Note that the variables are defined for each time period. Cases within the GAMS implementation variables ***AGCROPBUDGET*** and ***AGLVSTBUDGET*** are represented by this tableau column. Also implicit are the remainder of the agricultural sector submodel as in chapter 8 involving cost, processing, trade, domestic consumption, and transport.
- *Land from forest to ag* -- Land use change of crop or pasture land into forestry. When changing land use, these variables reflect removal of land from the agricultural

constraints in the current and all future time periods. They supply land into the constraint governing bare land available for afforestation. When crop land is being shifted, the entries in the equations for agricultural subregion and land quality differentiated crop land contain coefficients that are proportional to the initial relative abundance of that subregion's endowment of that quality of land in total region. When pasture land is being shifted, the coefficients reflect the removal of one acre from the forest land equation and supply into the pasture land equations proportional to the pasture share in the subregion at hand as it falls in the total region. These variables are defined for a movement of one acre of forest land. Geographically, they are defined on an 11 region basis. The ***LANDFROMAG*** and ***CONVRTFROMAG*** GAMS implementation variables are represented by this tableau column.

- *Land from forest to ag* -- Land use change of forest land into crop or pasture land. When changing land use, these variables reflect placement of land into the agricultural constraints in the current and all future time periods. They draw land from that represented by the constraint governing bare land for reforestation. When crop land is shifted, the entries in the equations for agricultural subregion and land quality differentiated crop land contain coefficients that enter land in a fashion proportional to the initial relative abundance of that subregion's endowment of that quality of land in the total subject region. When pasture land is being shifted, the coefficients reflect the addition of land into the pasture land equations according to the pasture share in the subregion at hand as it falls in the total region. It also withdraws land from the forest land equation. These variables are defined for a movement of one acre of crop or pasture quality land from forestry. Geographically, they are defined on an 11 region basis. The ***LANDTOAG*** and ***CONVRTTOAG*** GAMS implementation variables are represented by this tableau column.
- GHG payments -- Net GHG net payments as discussed above

The coefficients in this tableau of are

f -- cost, returns, and welfare generated in the forestry sector model across its many variables
i -- valuation of the terminal inventory in the form of area under product demand functions less production and manufacturing costs
a -- cost, returns, and welfare generated in the agricultural submodel across its many variables
ft --costs for transformation of forest land to agricultural land use
at -- costs for transformation of agricultural land to forest land use
g -- payments to net GHG increments as discussed above
Lnd -- initial forest land endowment
w -- forest land resource usage
fr -- forest resources available
fi -- forest standing inventory that persists beyond the last explicit model time period
Agln -- agricultural land endowment
S -- agricultural resource usage per unit production
Agr -- agricultural resource endowment
fse -- net GHG emissions by the forest sector

ase -- net GHG emissions by the agricultural sector
sq --agricultural sequestration lost (gained) when land use changes to forest (from forest)

Several features of the intersectoral land use change component of FASOMGHG merit additional comment:

- Land transferred to and from agriculture can shift uses more than once over the projection period, constrained in part by minimum harvest ages for timber. For example, timberland may be converted to agriculture for several time periods, and then could then shift back to timberland in a subsequent time period or vice versa.
- The inventory of agricultural lands contains some lands that are not suitable for forestry or agriculture because of climatic or topographical conditions.
- The types of forest that could be established on agricultural lands and the associated yield characteristics differ by region.
- Land only moves into and out of the category of land owned by nonindustrial private forest (NIPF) owners, in the land suitability classes for which land could start in forest and could potentially be converted to crop land and pasture land.
- Given that the forestry model is a multi-period model, such that when a forest stand is established, it may be 30 to 50 years before that stand is harvested. On the other hand, the agriculture model depicts cropping and livestock activity in a typical equilibrium year assuming that the same activity persists over a five year time period. This necessitates that the transfer variables remove or add agricultural land from/into all current and future land balances.

Table 9-1 Tableau illustrating dynamic meshing of forest and agriculture submodels

T

	Multi year forest production in periods 1-3	Multi year forest production in periods 2-4	Multi year forest production in periods 3-terminal	Multi year forest production in periods 4-terminal	Forest terminal inventory	Ag production in period 1	Ag production in period 2	Ag production in period 3	Ag production in period 4	Land from forest to ag period 1	Land from forest to ag period 2	Land from forest to ag period 3	Land from forest to ag period 4	Land from ag to forest period 1	Land from ag to forest period 2	Land from ag to forest period 3	Land from ag to forest period 4	GHG payment period 1	GHG payment period 2	GHG payment period 3	GHG payment period 4		
Welfare	f	f	f	f	i	a	a	a	A	-ft	-ft	-ft	-ft	-at	-at	-at	-at	+g	+g	+g	+g		
Forest land period 1	+1									+1				-1								<	Lnd
Forest resources period 1	+w																					<	Fr
Forest land period 2		+1									+1				-1							<	0
Forest resources period 2	+w	+w																				<	Fr
Forest land period 3	-1		+1									+1				-1						<	0
Forest resources period 3	+w	+w	+w																			<	Fr
Forest land period 4		-1		+1									+1				-1					<	0
Forest resources period 4		+w	+w	+w																		<	Fr
Forest terminal valuation			-fi	-fi	1																	<	0
Agricultural land period 1						+1				-1				+1								<	Agln
Agricultural resources period						+s																<	Agr
Agricultural land period 2							+1			-1	-1			+1	+1							<	Agln
Agricultural resources period							+s															<	Agr
Agricultural land period 3								+1		-1	-1	-1		+1	+1	+1						<	Agln
Agricultural resources period								+s														<	Agr
Agricultural land period 4									+1	-1	-1	-1	-1	+1	+1	+1	+1					<	Agln
Agricultural resources period									+s													<	Agr
GHG balance period 1	+fse					+ase				+sq				-sq				-1				=	0
GHG balance period 2	+fse	+fse				+ase	+ase			+sq	+sq			-sq	-sq				-1			=	0
GHG balance period 3	+fse	+fse	+fse			+ase	+ase	+ase		+sq	+sq	+sq		-sq	-sq	-sq				-1		=	0
GHG balance period 4	+fse	+fse	+fse	+fse		+ase	+ase	+ase	+ase	+sq	+sq	+sq	+sq	-sq	-sq	-sq	-sq				-1	=	0

9.2 Intersectoral commodity transfers

A limited number of commodities can shift from the agricultural commodity balances called ***AGPRODBAL*** to the forestry commodity balances called ***FORWDBALANCE***. These commodities must be defined on a regional basis in agriculture. The GAMS implementation variable that is involved with this commodity that it is called ***MOVCOMTOAG*** for forest commodities moved into the agricultural sector submodel and ***MOVCOMFRAG*** for agricultural commodities that are moved into the forest sector submodel. The specific commodities that can move are:

- The agricultural commodity hybrid poplar that can be transformed into the commodity ***AGRIFIBERSHORT***.
- The forestry commodity commodities pulp logs and milling residues that can move into the agricultural hybrid poplar and willow balances then enter into processing activities to produce ethanol or electricity.

These commodities move at a cost on a regional commodity specific basis in any time period.

9.3 Synchronizing different geographies

The agricultural and forestry sector submodel potentially each contain different geographies within the land base and log/crop/livestock production possibility set. Namely, in the initial time periods, the agricultural sector submodel operates at the 63 subregion level then later on an 11 region basis as discussed in Chapter 8. Simultaneously, the forestry model continually operates on an 11 region basis. This necessitates a procedure to place land transfers in appropriate places and stop the model from cherry picking where it would move the worst land from one sector into the best land in the other sector. To achieve this we require movement to always be in one fixed pattern by land type. Thus when land moves between the 11 region forest model and the 63 region agricultural model a synchronization procedure is used as is rather extensively explained in Chapter 8.

A limited number of commodities can shift from the agricultural commodity balances, called ***AGPRODBAL,*** to the forestry commodity balances, called ***FORWDBALANCE***. These commodities must be defined on a regional basis in agriculture. The GAMS implementation variable that is involved with this commodity is called ***MOVCOMTOAG*** for forest commodities moved into the agricultural sector submodel, and ***MOVCOMFRAG*** for agricultural commodities that are moved into the forest sector submodel. The specific commodities that can move are:

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9.4 Synchronizing different geographies

The agricultural and forestry sector submodels potentially each contain different geographies within the land base and log/crop/livestock production possibility set. Namely, in the initial time periods, the agricultural sector submodel operates at the 63 subregion level and then later at an 11 region level, as discussed in Chapter 8. Simultaneously, the forestry submodel continually operates on an 11 region basis. This necessitates a procedure to place land transfers in appropriate places and stop the model from cherry picking where it would move the worst land from one sector into the best land in the other sector. To achieve this, we require movement to always be in one fixed pattern by land type. Thus, when land moves between the 11 region forest model and the 63 region agricultural model, a synchronization procedure is used as is rather extensively explained in Chapter 8.

Briefly, this procedure affects one acre in a forestry region and fractions of that acre as they fall in the contained subregions (those that fall within the FASOMGHG region involved in the land transfer). These fractions are derived from a subregion's proportion of the total land in each region. The proportions are based on the initial inventory data and vary by type of land being transferred (e.g., crop or pasture). For example, if the PSW initial land area is apportioned 80% in Northern California and 20% in Southern California, then in the transfer of one acre of forest land to agriculture for the PSW forest land balance, it would be assigned so that 0.8 acre is added to the Northern California agricultural land balance and 0.2 acre in the Southern California balance. For crop land this would be further subdivided to reflect the incidence of land across quality types.

Also note the geographic basis for agricultural lands varies by time period. In the later time periods, the agricultural model reverts to the same 11 region definition for crop and livestock production as is used for log production in the forest model, so land transfers on a one to one basis. For crop land, this still would be subdivided to reflect, in this case, regional incidence of land across quality types.

9.5 Synchronizing time -- discounting and annuities

The dynamic characteristics of the submodels for GHG payments, agricultural sector, and forestry sector are somewhat different. This requires model features to synchronize the sectoral objective functions, as well as some alterations in the interpretations of levels of activity within the model time periods. Efforts were made in the forestry and agricultural submodels to represent typical steady-state activity in each year during a five year period.

On the forestry side, this necessitated model features regarding the volume of logs obtained from a harvested acre. Mainly, the harvested acreage gives the total acreage harvested during each five year period and if one multiplies that acreage by the per acre yield, one would get the total volume of logs across the five year period. To convert this to an annual amount, the yield terms were divided by five under the assumption that the acres harvested are cut at an equal rate in each year of the five year period. This is done in the GAMS implementation equations ***FORBALEXHRV, FORBALEXHPC, FORBALNEWHRV,*** and ***FORBALNEWHPC***. In turn, this annualized volume is entered into the wood products balance equation (***FORWDBALANCE***) via the harvested log variables ***FOREXHARVEST, FOREXHARVPC, FORNEWHARVEST,*** and ***FORNEWHARVPC.*** This leads to the processing and demand portions of the forest submodel having annualized amounts in a five year period. Also, the cost data for forestry were usually specified as annual costs, and in the case of the variable cost items, were adjusted to be average annual cost during a five year period. In turn, the forest returns were treated as constant annuities across the five year period and were multiplied by annuity factors. Subsequently, the returns across each of the five year periods were each multiplied by the relevant discount rate to adjust back to net present value on the basis of the first model time period. This is more precisely discussed in Chapter 7.

On the agricultural side the agricultural model represents typical activity during each year of a five year period. Thus, agricultural returns in each time period were also treated as a continuing annual annuity and were multiplied by a net present value for an annuity factor. This is more precisely discussed in Chapter 8.

The GHG payment part of the model was also treated with net preset value terms but was not converted to an annuity.

Therefore, the composite net present value returns were formed as the:

- Net present value of the agricultural submodel
- Plus the net present value of the forestry submodels

- Less the net present value of land transfers
- Less the net present value of the commodity transfers
- Plus the net present value of the GHG payments

and this in total forms the composite objective function ***WELFAR***.

9.6 Intersectoral tradeoffs under policies

FASOMGHG is solved with a composite objective function that spans across the GHG, agricultural sector, forestry sector, and intersectoral transfer submodels. When policies are imposed that provide incentives or require adjustments, the unifying force of the objective function causes the model to consider the possibility of adjusting activity anywhere within the forestry and agricultural sectors as well as the amount of land transfers and commodity movements. Such activities are also adjusted temporally and geographically. In turn, the model reequilibrates the land, commodity, and factor markets across all sectors, time periods, and geographic locations.

10 CHAPTER 10 APPROACHES USED TO INSURE TRACTABILITY

A number of features are used in the model to make it solve better or be asier to use. These include the use of

- Handling the supply and demand curves
- Seperable programming and associated steps for the supply and demand curves
- Crop and livestock mix relaxation
- Geographic expansion/collapse
- Time horizon and terminal conditions
- Substituting Memory for Time
- Arificial variable addition to insure feasibility
- Right hand side perturbation to avoid degenerate cycling

10.1 Handling the demand and supply curves

Given the dynamic nature of the supply and demand curves where they shifted out over time we felt a need to specify the demand and supply curves by passing them though a known point. We also found a need to handle the limits of integration so as to avoid numerical problems with large demand curve related integrals. This introduces a number of features are used in the context of handling the curves which merit discussion. We will present this in the context of a demand curve but make comments relative to a supply curve.

10.1.1 Demand and supply curve form

In FASOMGHG most of the demand and supply curves are assumed to be of the cost elasticity form (a few are assumed to be linear in the forestry sector)

$$P = P(Q) = F\,Q^{1/E}$$

where F is a constant and E the elasticity.

10.1.2 Passing the curve through a known point

The curves are set up so they pass through a given price quantity point (starting with the base year price and quantity and then later a quanity with a quantity growing at the historically observed rate and the price falling at the historically projected rate as discussed in the dynamic setion of the agricultural model chapter) with a given elasticity. Assume

$\hat{P}$, $\hat{Q}$ is the price and quantity point that the curve will pass through
E is the assumed elasticity of the curve

In turn given the assumed form

$$P = F\,Q^{1/E}$$

The we may solve for the unknown value of F getting

$$F = \hat{P}\,\hat{Q}^{-1/E}$$

which renders the original curve of the form

$$P = \hat{P}\,(Q/\hat{Q})^{1/E}$$

This curve form is used as it improves the numerical accuracy attributes as forming the ratio Q over $\hat{Q}$ and then exponentiating is subject to less round off error than would be individual exponentiations. It also facilitates gridpoint approximation as will be discussed below.

10.1.3 Integrating the functions

The formation of the objective function requires integration under the curves. The general form of the area under these curves is $\int_a^{Q^*} P(Q)\,dQ$ where

a and Q^* give the limits of integration with Q^* being the incumbent variable value in the model solution.
P(Q) gives the invese demand or supply curve
Q the quantity over which the area curve is swept.

When this curve is integrated one gets

$$\frac{\hat{P}}{(1+\frac{1}{E})}(Q/\hat{Q})^{(1+\frac{1}{E})} \text{ evaluated at } Q^* \text{ and } a$$

or

$$\frac{\hat{P}}{(1+\frac{1}{E})}(Q^*/\hat{Q})^{(1+\frac{1}{E})} - \frac{\hat{P}}{(1+\frac{1}{E})}(a/\hat{Q})^{(1+\frac{1}{E})}$$

For supply cases we use a lower integration limit of zero (a=0) and the term involving a drops out. However, for demand curves this is but is problemantic for demand cases as zero cannot be used since zero to a negative power is undefined so we must use a non zero lower limit. This involves truncating the evaluation as discussed next.

10.1.4 Truncating the demand evaluation

As stated just above we need a non zero lower limit for the demand curve integration. We choose this to both yield a defined value of the integral and to avoid numnerical problems. In particular, the consant elasticity demand curves become asymptotic to the axis as the quanity approaches zero. Thus, given inelastic curves for small limits of integration (Q* and a) one gets very large areas. This makes for very large welfare measures and objective function values. To avoid this we truncated the curve at the lower limit of integration. This was done by establishing a truncation factor at the larger of the quantity that is $1/10^{th}$ of $\hat{Q}$ or the quantity that raises the price to 10 times $\hat{P}$. Given this truncation factor is $K\hat{Q}$ the integration was reexpressed so that it is of the form

$$\int_{\hat{Q}/K}^{Q^*} \hat{P}(Q/\hat{Q})^{1/E}\, dQ$$

which after integration becomes

$$\frac{\hat{P}}{(1+\frac{1}{E})}(Q^*/\hat{Q})^{(1+\frac{1}{E})} - \frac{\hat{P}}{(1+\frac{1}{E})}K^{(1+\frac{1}{E})}$$

This is the formula that is used in the model. Note this formula requires that E cannot equal the numerical value of minus one as the denominator becomes undefined. This particular formulation has a couple of implications.

- The quantity cannot fall below 1/K times the base quantity that the curve is passed through. But assuming the demand curve is properly formed this is quite an unusual occurrence as going to $1/10^{th}$ the quantity or 10 times the price is generally unexpected.
- The area under the demand curve is not as large as one might get as one might truly integrated the curve out from zero as a very large block near the axis is cut off.

10.2 Adopting separable programming

Early experience with the nonlinear version of FASOM indicated that it would take a great deal of solution time, often measured in days to get a single solution. Thus was deemed to be unsatisfactory and we decided to see if formulation modifications would speed this up. We also have such a large model that in sheer size it strains or is beyond the capability of many available nonlinear solvers. As a consequence, we use a technique called seperable programming that allows the model to be approximated as a linear program. As a result given an advanced basis FASOMGHG now can be solved in less than an hour for many cases.

In FASOMGHG the demand and supply curves are based on own price elasticities only. This generates an objective function which in mathematical programming terms is separable. A well known result is that such a problem may be reformulated using a Taylor series approximation (Miller, 1963, Hadley 1964). We discuss this approach herein.

Approaches to nonlinear problems often utilize approximations. Such approximations may be either one-time or iterative (see McCarl and Spreen (1980) for a discussion of the differences). Seperable programming is a one time approximation and uses grid points, representing the inherent nonlinear phenomena as a discrete series of linearized steps. Furthermore, normal speerable programming requires a special solver that requires the adjacent grid points be employed. But given that we use downward sloping demand and upward sloping supply means we are doing seperable programming on concave functions. In turn, Hadley shows that adjacency will be a property of a linear programming solution and thus does not need to be specially handled.

Separable programming deals with problems in which the functions may be of any nonlinear form, but must be separable into functions of a single variable. For example, in a two variable case, the functions f(x,y) must be decomposable into h(x) + g(y). Separable programming is usually considered a nonlinear programming technique (Hadley, 1964); but is commonly used in an LP setting. The most commonly used form of separable programming that is employed here arose originally with Charnes and Lemke, and was extended by Miller(1963). The formulation yields an LP whenever the objective function terms are concave and the feasible set is convex (Hadley, 1964, p. 124).

Separable programming relies on a set of grid points and constructs an approximation between these points. The approximation is setup so that the approximated value arises from a first order Taylor series expansion equaling the value at the base point plus the slope divided by the difference from the base point. Suppose we wish to approximate the function at point X which falls between approximating points. This can be expressed algebraically for approximating the term f(X) with the term F(X) at the point X that falls between the grid points $\hat{X}_k$ and $\hat{X}_{k+1}$ by the formula

$$f(X) \cong F(X) = f\left(\hat{X}_k\right) + \frac{f(\hat{X}_k) - f(\hat{X}_{k+1})}{(\hat{X}_{k+1} - \hat{X}_k)}\left(X - \hat{X}_k\right)$$

Now suppose we write X as a convex combination of $\hat{X}_k$ and $\hat{X}_{k+1}$ using some new variables

$$\begin{array}{ccccccc} X & = & \lambda_k & \hat{X}_k & + & \lambda_{k+1} & \hat{X}_{k+1} & & \\ & & \lambda_k & & + & \lambda_{k+1} & & = & 1 \\ & & \lambda_k, & & & \lambda_{k+1} & & \geq & 0 \end{array}$$

where λ_k and λ_{k+1} are the new variables and give the the amount of the k^{th} and $k+1^{st}$ approximation points used.

Substituting this relationship for X as a function of λ and the grid points into the above appproximating equation for F(X) we get the equation

$$F(X) \cong \lambda_k f\left(\hat{X}_k\right) + \lambda_{k+1} f\left(\hat{X}_{k+1}\right)$$

where the function value is approximated by a convex combination of the function evaluated at the two adjacent grid points. This can be represented by a LP problem. Namely given the separable nonlinear problem (where in the context of FASOMGHG the f(X) terms are the nonlinear expressions for area under demand and supply curves)

$$
\begin{aligned}
\text{Max} \quad & \sum_j f_j(X_j) \\
\text{s.t.} \quad & \sum_j a_{ij} X_j \le b_i, \quad \text{for all i} \\
& X_j \ge 0
\end{aligned}
$$

and we may form the approximating problem

$$
\begin{aligned}
\text{Max} \quad & \sum_j \sum_\mu \lambda_{j\mu} f_j(\hat{X}_{j\mu}) \\
\text{s.t.} \quad & \sum_j \sum_\mu \lambda_{j\mu} a_{ij} \hat{X}_{j\mu} \le b_i, \quad \text{for all i} \\
& \sum_\mu \lambda_{j\mu} = 1 \quad \text{for all j} \\
& \lambda_{j\mu} \ge 0 \quad \text{for all j and } \mu
\end{aligned}
$$

where $\hat{X}_{j\mu}$ is the μ^{th} approximating point for X_j and

$$X_j = \sum_u \lambda_{j\mu} \hat{X}_{j\mu}$$

This formulation involves a change of variables. The variables $\lambda_{j\mu}$ give the amount of the μ^{th} grid point used in the approximation of the j^{th} variable. The term $f_j(\hat{X}_{j\mu})$ gives the values of the objective function (area under the curves) evaluated at the grid points. The new constraints on the λ variables cause a convex combination of the grid points to be chosen for each variable approximated. The demand functions must be downward sloping and the supply functions upward sloping, otherwise the nonzero λ's in the solution will not necessarily be adjacent; and the approximation will not work properly (Hadley, 1964).

In FASOMGHG, uniformly this is entered for all of the nonlinear objective function terms. What is involved for a demand curve is to select a set of points that surround the expected level of demand name defining a grid of such points. In turn, then we form the approximation using those points. We also alter the model definition slightly so it is as follows: Given the model

$$
\begin{aligned}
\text{Max} \quad & \sum_j f_j(X_j) \\
\text{s.t.} \quad & \sum_j a_{ij} X_j \le b_i, \quad \text{for all i} \\
& X_j \ge 0
\end{aligned}
$$

We alter it to include a new variable XS that is equated to X but only has the sperable objective function preserving the original X variable in the problem.

$$
\begin{array}{llllll}
Max & & \sum_j f_j(XS_j) & & & \\
s.t. & \sum_j a_{ij} X_j & & \leq & b_i & \text{for all } i \\
 & X_j & - \quad XS_j & = & 0 & \text{for all } j \\
 & X_j & , \quad XS_j & \geq & 0 & \text{for all} i
\end{array}
$$

Then we apply our approximation to this problem

$$
\begin{array}{llllll}
Max & & \sum_j \sum_\mu \lambda_{j\mu} f_j(\hat{X}S_{j\mu}) & & & \\
s.t. & \sum_j a_{ij} X_j & & \leq & b_i & \text{for all i} \\
 & X_j & - \quad \sum_\mu \lambda_{j\mu} \hat{X}S_{j\mu} & = & 0 & \text{for all j} \\
 & & \sum_\mu \lambda_{j\mu} & \leq & 1 & \text{for all j} \\
 & X_j & , \quad \lambda_{j\mu} & \geq & 0 & \text{for all j and } u
\end{array}
$$

---

where the gridpoints $\hat{X}S_{j\mu}$ are selected to surround the expected numerical values of the supply and demand quantities. In FASOMGHG, this is used to allow the original demand and supply variables to remain in the problem (for example ***AGDEMAND***) involves introduction of a new variable with an approximated nonlinear objective function term. The new variable is of the same dimension as the variable for which the term is being approximates plus the grid point dimension (***AGDEMANDS*** that has same dimension as ***AGDEMAND*** plus the added dimension ***step***). The naming then is the same as the original variable with an S and the ***step*** dimension added.

The FASOMGHG formulation uses grid points around the expected value of X to approximate the associated functions. Such grid points should provide a reasonable approximation of the function in the domain of the answer, including points both close to the expected answer as well as points depicting functional extremes (Geoffrion (1977) discusses the importance of the extreme points). Even spacing of the grid points is not required. Thus, one could approximate a curve at the points 10, 2, 1, 0.95, 0.50, 0.10, 0.02 and 0.01. We will discuss formation of the grid points below.

10.3 Selecting grid points

As shown above the integral of the subject curves for the demand curve cases is

$$\frac{\hat{P}}{(1+\frac{1}{E})}(Q^*/\hat{Q})^{(1+\frac{1}{E})} - \frac{\hat{P}}{(1+\frac{1}{E})}K^{-(1+\frac{1}{E})}$$

wherein the second term is merely a constant and for the supply curve cases this is

$$\frac{\hat{P}}{(1+\frac{1}{E})}(Q^*/\hat{Q})^{(1+\frac{1}{E})}$$

Thus the general term we need to approximate in the objective function is of the form just above. Now in choosing grid points for the decision variable Q we may either specify alternative ratios of $Q^*/\hat{Q}$ where Q^* equals the base value of $\hat{Q}$ times the gridpoint factor M and M=1 gives the base value. We choose to do the latter. Namely given the following demand related model component

$$\begin{array}{llll} \text{Max} & \sum_j \frac{\hat{P}_j}{(1+\frac{1}{E_j})}(Q_j/\hat{Q}_j)^{(1+\frac{1}{E_j})} & & \\ \text{s.t.} & \sum_j a_{ij}Q_j & \leq b_i, & \text{for all i} \\ & Q_j & \geq K_j\hat{Q}_j & \text{for all j} \end{array}$$

Where the

j subscript identifies the jth commodity

$\hat{P}_j$, $\hat{Q}_j$ is the price quantiy point the demand curve is passed though

Q_j is the level of demand for which we wish an integral

K_j is the truncation lower level on demand as a proportion of $\hat{Q}_j$

The constraint $\sum_j a_{ij}Q_j \leq b_i$ is simply an indicator of the rest of the model

We add in the new variable QS which merely has the nonlinear terms

$$
\begin{array}{llllll}
Max & \sum_j \frac{\hat{P}_j}{(1+\frac{1}{E_j})} (QS_j/\hat{Q}_j)^{(1+\frac{1}{E_j})} & & & & \\
s.t. & \sum_j a_{ij} Q_j & & \leq & b_i & \text{for all i} \\
 & Q_j \quad - & QS_j & = & 0 & \text{for all j} \\
 & & QS_j & \geq & K_j \hat{Q}_j & \text{for all j} \\
 & Q_j \quad , & QS_j & \geq & 0 & \text{for all j}
\end{array}
$$

Then we specify values of grid points M_{ju} as ratios of $QS_j/\hat{Q}_j$

$$M_{ju} = \hat{Q}S_{ju}/\hat{Q}_j \qquad \text{or} \qquad \hat{Q}S_{ju} = M_{ju} * \hat{Q}_j$$

And we introduce the seperable programming step variable λ and a convexity constraint

$$
\begin{array}{llllll}
Max & \sum_j \sum_u \frac{\hat{P}_j}{(1+\frac{1}{E_j})} (M_{ju})^{(1+\frac{1}{E_j})} \lambda_{ju} & & & & \\
s.t. & \sum_j a_{ij} Q_j & & \leq & b_i & \text{for all i} \\
 & Q_j \quad - & \sum_u M_{ju} \hat{Q}_j \lambda_{ju} & = & 0 & \text{for all j} \\
 & & \sum_u M_{ju} \hat{Q}_j \lambda_{ju} & \geq & K_j \hat{Q}_j & \text{for all j} \\
 & & \sum_u \lambda_{ju} & = & 1 & \text{for all j} \\
 & Q_j \quad , & \lambda_{ju} & \geq & 0 &
\end{array}
$$

This is what is done in the FASOMGHG objective function with several small variants

- The term involving the K_j truncation factor is dropped as the first gridpoint value is that factor and it is impossible for demand to be smaller than that given the formulation.
- The objective function has a constant added to it to take care of the truncation of the area as discussed above.
- For supply curves all is as above but no truncation factor is used. However the lowest gridpoint does supply a lower bound on the level of supply.
- We actually use elasticity dependent grid points with lower quantity spreads for more inelastic curves.
- The gridpoints are specified in the file ***model_seperable.gms*** and are resident in the arrays ***qincag*** and ***qincwood*** for the forest and agricultural parts of the model respectively.

- The number of grid points is determined by the size of the set ***step***.
- The grid approximation variables corresponding to λ in the above conceptual model are

  FORWDNWCS
  FORWDDEMANDS
  FORWDSUPPLYS
  FORWDLOGSUPPLYS
  AGDEMANDS
  AGSUPPLYS
  AGRESSEPSUPPLY

  The identities linking these to the original variables are defined for all cases but the non-wood input case (***FORWDNWCS***) which is defined originally with steps present and are

  FORWDSUPEQ
  FORWDSUPPLY
  FORWDDEMEQ
  FORWDLOGSUPEQ
  AGSDIDENTITY
  AGRESIDENTITY

  Convexty is imposed in

  FORWDNWCCONVEX
  FORWDSCONVEX
  FORWDDCONVEX
  FORWDSLOGCONVEX
  AGSDCONVEX
  AGRESCONVEX

10.4 Crop and livestock mixes – concept and relaxation

Crop and livestock mixes are used in the model to prevent difficulties with aggregation and preventing extreme regional specialization. The conceptual reason for and theory behind the use of mixes is discussed in chapter 5. Their use in irrigated and total crop modeling and their risk in livestock context is discussed in Chapter 8. Numerical aspects of the implementation of mixes are discussed here.

Some additional mix related features were included in FASOMGHG to facilitate numerical solutions and to relax the stringency of the mix restrictions as time advances. These involve

- Treating the crop mixes as upper and lower limits
- Relaxing the mixes in later time periods

These are discussed in the sections just below.

10.4.1 Upper and lower limits

The crop mixes are treated as upper and lower bounds on the acreage of crops that can be ground. In particular the crop acreage must fall in a range between 90% and 100% of the crop the acreage from the mix. This allows some slight relaxation of the mixes to facilitate the model from not getting into a numerically infeasable situation. This is implemented by defining an upper ***(AGCRPMIXUP)*** and lower bound ***(AGCRPMIXLO)*** constraint on the mix as well as a constraint that requires that the total acreage is the crops covered equals the total acreage in the mix ***(AGCRPMIXTOT)***.

10.4.2 Temporal relaxation

The crop and livestock mixes are a particularly dense and difficult part of the model. Their imposition is somewhat questionable for distant future time periods. Namely new technological developments may significantly alter the production possibility set (e.g. 80 years ago soybeans were not produced in any significant quantities in the US and are now a major crop). In response to these observations, the decision was made to set up the empirical FASOMGHG programming model with the crop and livestock mixes only for time periods in the first 20 years, then drop them for the remaining explicit time periods. That means that solutions for periods beyond 2020 will show a higher degree of specialization. Such a decision makes FASOMGHG easier to solve, and reduces the future influence of the crop and livestock mix constraints. These mixes are maintained in the first 20 years as we felt that yielded the most realistic and detailed solutions for those time periods.

10.5 Geographic expansion/collapse

The FASOMGHG 63 subregion agricultural production representation creates a large submodel and makes FASOMGHG hard to solve. In the interests of improved solution efficiency, this level of detail was only maintained for the first 20 years. Subsequently, the agricultural sector production representation was aggregated to an 11 region basis but still represented the full diversity of production possibilities. The data for prices, production budgets, transport costs, etc. defining the aggregate 11 regions was formed as a weighted average across the 63 region data set where the weighting was by quanitiy of acreage or associated item in each region weighted up from the subregions in that region. The data on resource availability is a simple sum across the subregions data in that regions. This means that production is represented in the PSW region is initially modeled in Northern and Southern California but then later this is aggregated to the total PSW region with the same set of crop and livestock production possibilities but aggregated data. This was done to facilitate model solution with details retained in the initial years to yield the most detailed and realistic information as possible in the first 20 years.

10.6 Time horizon and terminal conditions

The decision on how FASOMGHG should represent the passage of time and management alternatives over time greatly affects the tractability of the resultant programming model. Conceptually, one should depict land-use decision making particularly that involving forest planting dates and rotation lengths as if the decision maker was considering returns over an infinite time horizon. Such consideration is necessary to avoid the incidence of biased behavior within the model solution. For example if we were to only consider 50 years one would undoubtedly find solutions where no timber stands were planted that could not be harvested within the 50 year period. Further such a solution would reflected little timber being established after year 30 and almost everything scheduled for harvest somewhere in the explicit time periods modeled. However while it is desirable to reflect infinitely long time periods, the model easily becomes too large to be tractable. It is also difficult to obey the conventional dynamic rule that one should depict a long enough time period that a lengthening of that explicit time period does not affect the solution in the initial model time periods that are of decision-making focus. Experience with FASOMGHG showed we could not do this and generate a model that would solve in reasonable time. As a consequence and the FASOMGHG strategy involved three time period related considerations

- How long the model goes i.e. how long a time period is explicitly depicted
- How fine the resolution is within that explicit time period.
- How to value land and assets in unharvested timber stands or in agriculture at the end of the explicit model time period.

Regarding these questions, the FASOMGHG implementers generally felt that the explicit model time periods had to be extended until so they were enough to get about two full rotations represented for stands with the longest expected rotation lengths. Given the longest rotations are in the neighborhood of 40 of 50 years, our choice has usually been to depict 100 years. Simultaneously, while going 100 years it's also important to have a fine enough disaggregation of time periods to adequately represent harvest possibilities for the shortest rotation forest stands. This involves rotations in the South for pulpwood production in the neighborhood of 20 to 30 years. In the face of this and experience with an earlier 10-year granularity version we decided to represent five-year granularity. Consequently the FASOMGHG programming model explicitly represents 100 years of production in 20 explicit five year periods.

We also need to value ending inventory of unharvested forest stands and continuing land use in agriculture. To provide such valuation, FASOMGHG is structured under the assumption that forest management is, from the last period onward, a continuous or constant flow process with a forest inventory that is fully regulated at typical rotation lengths observed for the region (see Adams et al. [1996]). The terminal value of land remaining in agriculture is formed by assuming that the last period persists forever. In both cases, demand curves are used to reflect diminishing valuation as the ending inventory or allocation of agricultural land increases.

10.7 Substituting Memory for Time

One strategy used to ensure tractability is to pre-calculate items that take substantial time to compute and are complex, repetitive, and never or infrequently changing. This is done by precalculating such items into arrays then only the results in the formulation. For example we precalculate the conditions indicating whixh forest stands exist and place them into the ***isexist*** and ***isnew*** tuples for later use in the model. Similarly, we pre-calculate stand level forest cost elements across a number of cost categories. This placing summary calculations into memory then only using the saved results in the model set up.

10.8 Artificial variable addition to insure feasibility

The ability to specify lower bounds on particular forest or agricultural product consumption levels raises the specter that empirical programming model realizations may be set up that are infeasible. As a consequence, a number of artificial variables are permanently resident in the model formulation that permit satisfaction of minimum consumption constraints even though it's not technically possible. In turn, when these artificails are in solution indicating that some of the minimum consumption levels cannot be satisfied their presence distorts the market clearing producy and factor shadow prices allowing one to diagnose the cause of the model infeasibility. For a conceptual discussion of this issue along with examples see McCarl.

10.9 Right hand side perturbation to avoid degenerate cycling

One concern that emerged in the 1950s and 60s involved the possibility of degenerate cycling within mathematical programming computer algorithms and subsequent failure. Some of the literature recommended one avoid this problem through perturbation of the right hand sides (adding small numbers). Experience over the years has found this is helpful with particular solvers (note we are currently using CPLEX which does this automatically and makes the procedure we describe next somewhat unnecessary). Such a perturbation is permanently implemented in FASOMGHG. For example in many of the supply demand balance constraints that ordinarily would have zeros on the right hand sides theye actually implemented with small numbers on the right hand side. These numbers are selected so that they do not significantly bias the solution results (i.e. we do not care about an extra 1/10th of a bushel of corn in the face of a 9 billion bushel corn crop) but make the problem easier to solve. These generally involve a parameter called ***twid***.

11 CHAPTER 10 MODELING OF EFFECTS OF CLIMATIC CHANGE

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12 CHAPTER 11 MODELING LAGGED PRODUCTION RESTRICTIONS

SECTION 4: DATA SPECIFICATON

This section presents discussion of the procedures used in specifying the data used.

For starters, we can use the recently expanded write-up from the Assessment Report which follows the basic structure below (I will send separately). But we will need to be more detailed than that for SAB review. So, for a first pass, provide a fair amount of detail about the underlying data (NASS, FIA, …) and models (TAMM, ATLAS, Century, EPIC, FORCARB,…) as possible. If this proves unwieldy, we will develop a strategy for assigning details to appendices later.

13 CHAPTER 12 GHG DATA SPECIFICATION

Bruce, please note that Ch 13 is titled "GHG Data Specification" but only includes our stuff on forest Carbon. Also, where do we report on the data that J Chmelik collected on fuel-related emissions from forestry?

13.1 Forest Carbon Detail

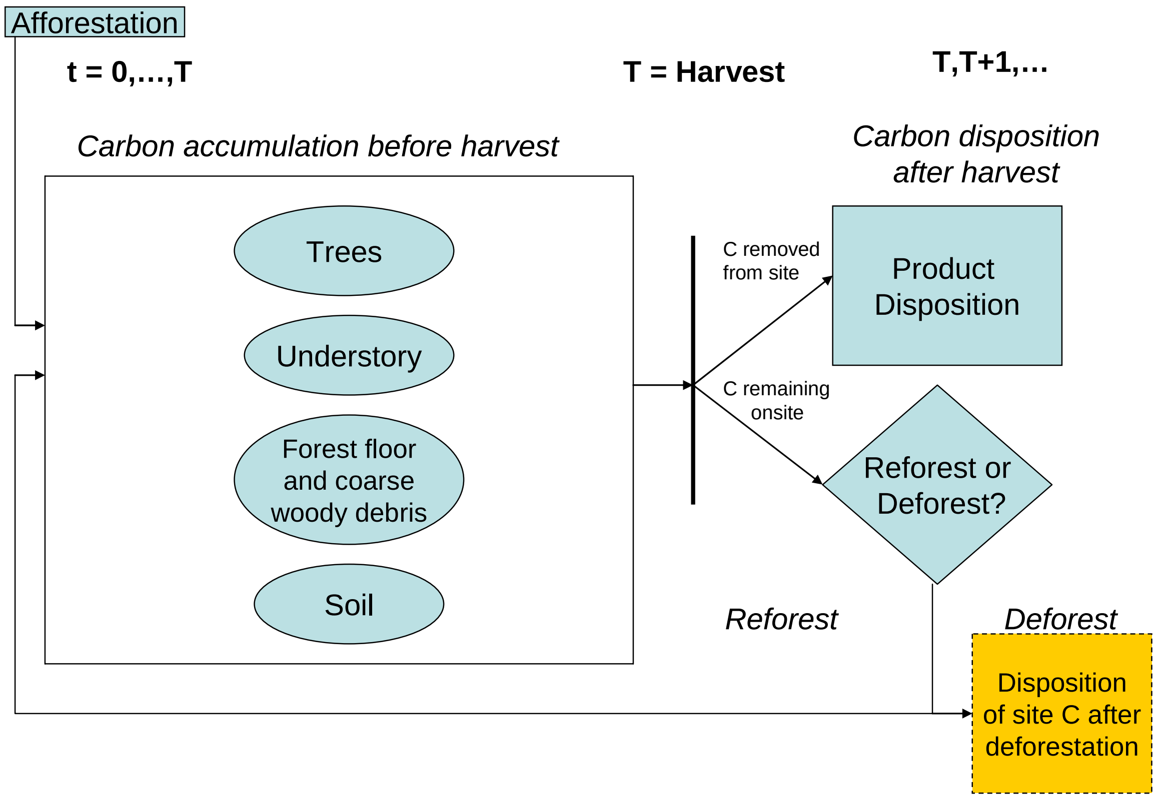
The carbon sector is designed to provide an accounting system for major carbon pools in private timberland and crop land. It is structured so that a variety of policy instruments can be evaluated including constraints for total carbon pools or the rate of accumulation of carbon form year to year. These constraints can be consistent with a variety of policy instruments that may vary carbon management by region, owner, land class, etc. In addition, FASOMGHG's can evaluate the effects of GHG payment policy.

The basic functions of the carbon accounting component of the FASOMGHG include:

- carbon accumulation in trees, understory, forest floor, and soil on existing forest stands in the existing private timberland inventory during the simulation period,
- carbon accumulation in trees, understory, forest floor, and soil on reforested and afforested stands during the simulation period,
- carbon losses over time associated with harvested logs transformed into wood or paper products, and
- carbon profiles for land transferring between forests and agriculture and developed land uses.

As shown in Figure 13-1, the forest carbon accounting is separated into two fundamental parts: (1) the accumulation of carbon as forested stands mature prior to harvest and (2) the disposition of carbon into various pools after the point of harvest. We discuss each component below and provide details of the calculations and data sources.

Figure 13-1. Forest Carbon Accounting

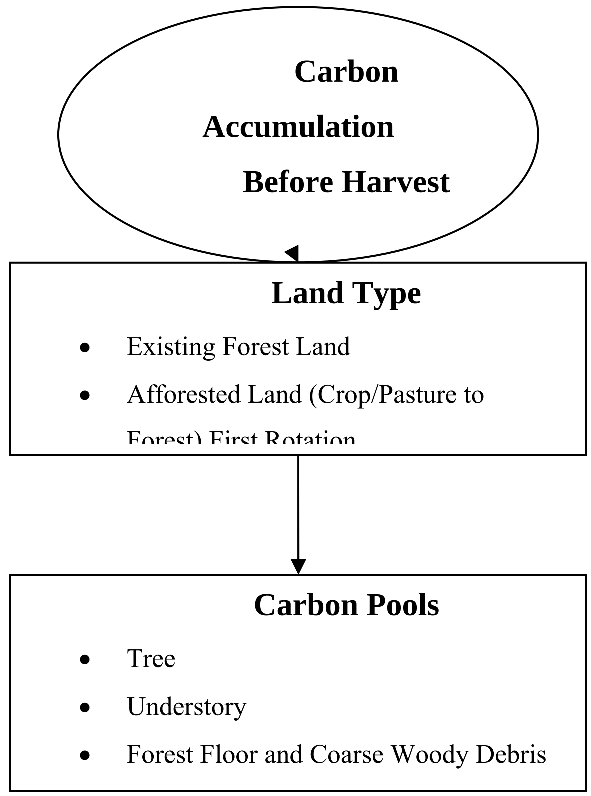


13.2 Carbon Accumulation Before Harvest

This section outlines the carbon accumulation process on three types of land: existing forest land, agricultural land that is converted to forest land, and forest land that continues to be used as forest land after initial harvests. Within each land type, carbon accumulates in four carbon pools:

- Trees,
- Understory,
- Forest Floor and Coarse Woody Debris, and
- Soil

Figure 13-2. Carbon Accumulation Before Harvest



13.2.1 Trees

Onsite carbon accounting closely mirrors the FORCARB system employed by the USFS in their periodic aggregate assessments of forest carbon sequestration. The onsite carbon accounting in FORCARB has been developed over the years by USFS researchers Richard Birdsey, Linda Heath, and Jim Smith. Most recently, Smith et al 2003 have revised the tree carbon component of the system to more flexibly express carbon in terms of (live and dead) biomass density equations.

In FASOMGHG, tree carbon on land is a function of three factors: 1) merchantable volume, 2) the ratio of growing stock volume to merchantable volume, 3) and parameters of a forest volume-to-biomass model developed by USFS researchers (Smith, et al, 2003). Merchantable volume, by age, on each representative stand is obtained form the timber growth and yield tables in the model described in Chapter X. The volume factors and biomass model parameters vary by species and region and are obtained from Birdsey (1996) and Smith, et al (2003). The corresponding equations, variable descriptions, units, and sources used to compute tree carbon are described below.

13.2.1.1 Total Growing Stock Volume in Standing Trees

The key input for the forest volume-to-biomass model is the total timber volume in standing trees. This value is expressed using the following approach:

$$V^T = V^M * F * 1{,}000 / U^A \quad [1]$$

The variables in this equation are defined in Table 13-1.

Table 13-1. Total Timber Volume Variables and Parameters

Symbol	Description	Units	Source	Comment
V^T	**Total timber volume**	**m^3/ha**	**Calculated**	**Volume must be expressed in m3/ha to be used in Forest volume-to-biomass model.**
V^M	**Merchantable timber volume**	**1,000 ft^3/acre**	**Growth and yield tables from timber inventory data. (see Chapter X)**	
F	**Conversion factor: merchantable to total timber volume**	**--**	**Birdsey 1996, specific values displayed in Table 2**	**Assumed constant over age.**
U^A	**Units conversion factor**	**14.29**	**m^3/ha = 14.29 ft^3/acre**	

The conversion factors (F) for Equation (1) are differentiated by region and species and are reported in Table 13-2.

Table 13-2. Total Volume Conversion Factors by Region and Forest Type

FASOMGHG Region	Softwood	Hardwood
North East	2.193	2.14
Lake States	2.514	2.418
Corn Belt	2.601	2.651
South East	1.682	2.233
South Central	1.786	2.896
Rocky Mountain	2.254	2.214
Pacific Northwest-west	1.675	2.279
Pacific Northwest-east	1.675	2.279
Pacific Southwest	1.675	2.279

Source: Birdsey(1996 a,b)). This work cites the earlier work of Birdsey (1992a and b), on which some of the initial carbon calculations are based. Selected values from Tables 1.2 and 1.3.

13.2.1.2 Live and Standing Dead Trees

Carbon in live and standing dead trees is calculated using the parameters of the forest volume-to-biomass model equations for live and dead tree mass densities (above- and belowground) in Smith, et al (2003). The parameters used are weighted parameters for the FASOMGHG region/forest type designations. Forest land area data reported by RPA (Miles, 2003) are used to calculated the appropriate weights. Birdsey's assumption that mass of wood is approximately 50 percent carbon is used to derive the associated levels of carbon (Birdsey, [1992]).

$$D^L = F^w \times (G^{vbw} + (1\text{-}exp(-V^T)/H^{vbw})) \quad [2]$$

$$D^D = D^L \times A^{vbw} \times exp(-((V^T/B^w)\text{^}C^{vbw})) \quad [3]$$

$$C^R = (D^L + D^D)/U^B \times 0.5 \quad [4]$$

Table 13-3. Tree Carbon Variables and Parameters

Symbol	Description	Units	Source
D^L	**Live-tree mass density (above- and belowground)**	**Mg/ha**	**Calculated**
D^D	**Dead-tree mass density (above- and belowground)**	**Mg/ha**	**Calculated**
C^R	**Total tree carbon**	**Mg/ac**	**Calculated**
V^T	**Total timber volume**	**m^3/ha**	**See Equation (1)**
F^{vbw},G^{vbw}, H^{vbw}	**Weighted live tree density parameters from volume-to-biomass equations**	**--**	**Smith et al (2003) Table 7 weighted by forest land area data from RPA (Miles, 2003) Tables 5 and 6. We report values in Table 3a.**
A^{vbw},B^{vbw}, C^{vbw}	**Weighted dead tree mass density parameters from volume-to-biomass equations**	**--**	**Smith et al (2003) Table 8 weighted by forest land area data from RPA (Miles, 2003) Tables 5 and 6. We report values in Table 3a.**
U^B	**Units conversion factor**	**1 hectare (ha) = 2.471 acres**	**--**

The weighted parameters used are reported in Table 3a.

Table 13-3a. FASOMGHG Live and Dead Tree Density Parameters

FASOMGHG GHG Region	FASOMGHG GHG Forest Type	Owner	A	B	C	F	G	H
Cornbelt	Hardwood	Public	0.4130	222.20	0.977	406.6	0.0570	248.4
Cornbelt	Hardwood	Private	0.2540	234.02	1.038	377.2	0.0590	224.3
Cornbelt	Softwood	Public	0.2500	241.43	0.691	409.0	0.0480	319.0
Cornbelt	Softwood	Private	0.2500	241.43	0.691	409.0	0.0480	319.0
Lake States	Hardwood	Public	0.4130	222.20	0.977	406.6	0.0570	248.4
Lake States	Hardwood	Private	0.2540	234.02	1.038	377.2	0.0590	224.3
Lake States	Softwood	Public	0.2500	241.43	0.691	409.0	0.0480	319.0
Lake States	Softwood	Private	0.2500	241.43	0.691	409.0	0.0480	319.0
Northeast	Hardwood	Public	0.0910	354.15	2.156	522.4	0.0380	348.3
Northeast	Hardwood	Private	0.0910	354.15	2.156	451.8	0.0480	284.7
Northeast	Softwood	Public	0.1330	228.25	1.368	354.1	0.0390	208.6
Northeast	Softwood	Private	0.1330	228.25	1.368	354.1	0.0390	208.6
Rocky Mountain	Hardwood	Public	0.3400	1095.89	2.478	1097.5	0.1070	996.0
Rocky Mountain	Hardwood	Private	0.3400	1095.89	2.478	1097.5	0.1070	996.0
Rocky Mountain	Softwood	Public	5.8740	50.10	0.296	795.4	0.0520	725-1
Rocky Mountain	Softwood	Private	5.9280	11.21	0.258	809.1	0.0500	733.2
Pacific Southwest	Hardwood	Public	1.0480	2.67	0.230	1463.7		1119.4
Pacific Southwest	Hardwood	Private	1.0480	2.67	0.230	1463.7		1119.4
Pacific Southwest	Softwood	Public	1.1940	688.79	0.308	1581.9	0.0150	1745-3
Pacific Southwest	Softwood	Private	1.1940	688.79	0.308	1581.9	0.0150	1745-3
Pacific Northwest West	Douglas Fir	Public	0.2840	848.73	0.379	5062.8	0.0050	6830.2
Pacific Northwest West	Douglas Fir	Private	0.2840	848.73	0.379	1191.2	0.0190	1251.2
Pacific Northwest West	Hardwood	Public	0.6790	1.84	0.179	9977.5	0.0060	12560.4
Pacific Northwest West	Hardwood	Private	0.6790	1.84	0.179	9977.5	0.0060	12560.4
Pacific Northwest West	Other Softwoods	Public	0.5130	320.98	0.225	4902.2	0.0090	7325.7
Pacific Northwest West	Other Softwoods	Private	0.5130	320.98	0.225	4728.3	0.0100	7048.4
Pacific Northwest West	Softwood	Public	0.2840	848.73	0.379	5062.8	0.0050	6830.2
Pacific Northwest West	Softwood	Private	0.2840	848.73	0.379	1191.2	0.0190	1251.2
Pacific Northwest East	Hardwood	Public	0.9230	1.00	0.585	614.0	0.0530	660.4
Pacific Northwest East	Hardwood	Private	0.9230	1.00	0.585	614.0	0.0530	660.4

(continued)

Table 13-3a (continued)

FASOMGHG GHG Region	FASOMGHG GHG Forest Type	Owner	A	B	C	F	G	H
Pacific Northwest East	Softwood	Public	3.2290	32.94	0.246	2137.6	0.0040	2768.8
Pacific Northwest East	Softwood	Private	1.5960	111.35	0.415	444.7	0.0160	393.4
South Central	Bottomland Hardwood	Public	0.3290	30.12	0.305	313.5	0.1020	147.9
South Central	Bottomland Hardwood	Private	0.1490	145.42	0.484	314.5	0.1090	174.9
South Central	Hardwood	Public	0.3290	30.12	0.305	313.5	0.1020	147.9
South Central	Hardwood	Private	0.1490	145.42	0.484	314.5	0.1090	174.9
South Central	Natural Pine	Public	0.0470	974.52	1.355	363.1	0.1130	480.0
South Central	Natural Pine	Private	0.0550	424.29	1.901	358.3	0.0940	421.9
South Central	Oak Pine	Public	0.0620	835.98	0.892	282.3	0.0900	197.4
South Central	Oak Pine	Private	0.0620	835.98	0.892	282.3	0.0900	197.4
South Central	Planted Pine	Public	0.0630	5137.75	0.136	161.8	0.1400	116.1
South Central	Planted Pine	Private	0.0630	5137.75	0.136	161.8	0.1400	116.1
South Central	Softwood	Public	0.0550	3056.14	0.745	262.5	0.1260	298.1
South Central	Softwood	Private	0.0590	2781.02	1.018	260.1	0.1170	269.0
South Central	Upland Hardwood	Public	0.0620	313.09	2.438	241.0	0.0970	141.4
South Central	Upland Hardwood	Private	0.0670	315.70	1.314	193.5	0.1520	112.8
Southeast	Bottomland Hardwood	Public	0.0770	347.43	1.104	429.2	0.0570	291.6
Southeast	Bottomland Hardwood	Private	0.0770	347.43	1.104	963.2	0.0260	800.4
Southeast	Hardwood	Public	0.0770	347.43	1.104	429.2	0.0570	291.6
Southeast	Hardwood	Private	0.0770	347.43	1.104	963.2	0.0260	800.4
Southeast	Natural Pine	Public	0.0510	826.84	1.353	1213.0	0.0140	1610.1
Southeast	Natural Pine	Private	0.0510	826.84	1.353	356.4	0.0430	340.9
Southeast	Oak Pine	Public	0.0510	826.84	1.353	420.1	0.0350	309.8
Southeast	Oak Pine	Private	0.0510	826.84	1.353	420.1	0.0350	309.8
Southeast	Planted Pine	Public	0.0510	826.84	1.353	226.4	0.0670	183.7
Southeast	Planted Pine	Private	0.0510	826.84	1.353	226.4	0.0670	183.7
Southeast	Softwood	Public	0.0510	826.84	1.353	719.7	0.0400	896.9
Southeast	Softwood	Private	0.0510	826.84	1.353	291.4	0.0550	262.3
Southeast	Upland Hardwood	Public	0.0770	347.43	1.104	342.3	0.0900	261.8
Southeast	Upland Hardwood	Private	0.0770	347.43	1.104	352.6	0.0610	285.8

Source: Author calculations using Smith et al (2003) and forest land area data from RPA (Miles, 2003).

As noted in Smith, et al (2004b), correction factors should be applied to the biomass model when the distribution of volume of an area is unknown. However, FASOMGHG aggregates data by age class which means that volumes are narrowly distributed. As a result, there is no need to apply these factors within FASOMGHG (Smith, 2004a).

13.2.2 Understory

Understory vegetation comprises the smallest component of total carbon stock and includes all live vegetation except trees larger than seedlings. FASOMGHG makes the assumption that understory carbon is a fixed fraction of live tree carbon and uses published ratios reported in US EPA (2003) as the basis for these calculations. Weighted ratios for FASOMGHG regions/forest types are created using forest land area data reported by RPA (Miles, 2003).

$$C^U = D^L/U^B \times 0.5*R^{Uw} \quad [5]$$

The variables in this equation are defined in Table 13-4. The weighted parameters used are reported in Table 13-4a.

Table 13-4. Understory Carbon Variables and Parameters

Symbol	Description	Units	Source
C^U	Total Understory Carbon	Mg/ac	Calculated
D^L	Live-tree mass density (above- and belowground)	Mg/ha	See Eq.2
U^B	Units conversion factor	1 hectare (ha) = 2.471 acres	--
R^{Uw}	Weighted ratio of understory carbon to live tree carbon	percent	EPA (2003) Table O-2 weighted by forest land area data from RPA (Miles, 2003) Tables 5 and 6.

Table 13-4a. Weighted Ratio of Understory to Live Tree Carbon (Percent)

FASOMGHG REGION	Softwood	Hardwood	Planted Pine	Natural Pine	Oak Pine	Douglas Fir	Bottomland Hardwood	Upland Hardwood	Other Softwoods
North East	2.6	2.2	NA	NA	NA	NA	NA	NA	NA
Lake States	2.1	2.4	NA	NA	NA	NA	NA	NA	NA
Corn Belt	2.1	2.4	NA	NA	NA	NA	NA	NA	NA
South East	NA	NA	6.8	6.8	4.4	NA	2.2	4.4	NA
South Central	NA	NA	5.9	5.9	4.4	NA	2.2	3.7	NA
Rocky Mountain	5.7	9.2	NA	NA	NA	NA	NA	NA	NA
Pacific Northwest-	NA	4.5	NA	NA	NA	2.0	NA	NA	3.2

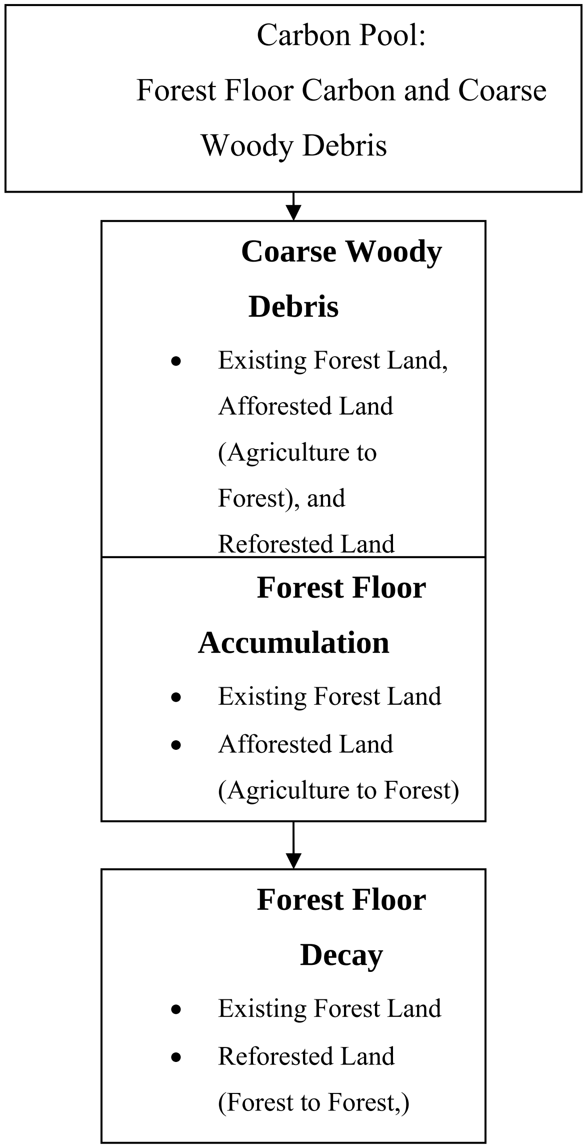
West									
Pacific Northwest-East	3.0	4.5	NA	NA	NA	NA	NA	NA	NA
Pacific Southwest	5.0	2.9	NA	NA	NA	NA	NA	NA	NA

Source: Author calculations using EPA (2003) and forest land area data from RPA (Miles, 2003).

13.2.3 Forest Floor and Coarse Woody Debris

Forest floor carbon constitutes the third largest carbon storage pool, but is much smaller than tree or soil carbon pools. Smith and Heath (2002) have recently developed a model estimating forest floor carbon mass and it forms the basis for forest floor carbon estimates in FASOMGHG. The model's definition of forest floor excludes coarse woody debris materials, that is, pieces of down dead wood that are not attached to trees. In order to account for this material, coarse woody debris is assumed to be a fixed fraction of live tree carbon and is added to the forest floor carbon values generated by Smith and Heath's forest floor model. Figure 13-3 describes the essential components of these calculations.

Figure 13-3. Carbon Accumulation in Forest Floor and Coarse Woody Debris



The model for net accumulation of forest floor carbon is a continuous and increasing function of age. The rate of accumulation eventually approaches zero (i.e. and a steady state level of forest carbon reached):

$$C^{FFA} = (A^{ffw} \times Age)/(B^{ffw} + Age) \times U^{B} \quad [6]$$

The variables in this equation are defined in Table 13-5a.

Table 13-5a. Forest Floor Carbon Variables and Parameters: Net Accumulation

Symbol	Description	Units	Source
C^{FFA}	Total Forest Floor Carbon net accumulation	Mg/ac	Calculated
Age	Age of Stand	Years	--
A^{ffw},B^{ffw}	Weighted forest floor carbon model coefficients	--	Smith and Heath (2002) Table 4 weighted by forest land area data from RPA (Miles, 2003) Tables 5 and 6. We report values in Table 6a.
U^{B}	Units conversion factor	1 hectare (ha) = 2.471 acres	--

Forest floor carbon mass following clearcutting is assumed to begin at a mature forest level of carbon and decay is described using exponential function of time and average mature forest floor carbon mass:

$$C^{FFR} = (C^{ffw} \times exp^{-(Age/Dffw)}) \times U^{B} \qquad [7]$$

Since this equation accounts for decay of forest floor carbon mass existing prior to clearcut, this equation only applies to land with existing forests or land that is reforested. Land that has moved from agriculture to forestry does not include this calculation during the first rotation.

The variables in this equation are defined in Table 13-5b.

Table 13-5b. Forest Floor Carbon Variables and Parameters: Decay of Forest Floor Carbon Mass Existing Prior to Clearcut

Symbol	Description	Units	Source
C^{FFR}	Total Forest Floor Carbon, residual	Mg/ac	Calculated
Age	Age of Stand	Years	--
C^{ffw},D^{ffw}	Weighted forest floor carbon mass coefficients	--	Smith and Heath (2002) Table 4 weighted by forest land area data from RPA (Miles, 2003) Tables 5 and 6. We report values in Table 6a.
U^{B}	Units conversion factor	1 hectare (ha) = 2.471 acres	

The weighted parameters used are reported in Table 13-5c.

Table 13-5c.Forest Floor Carbon Model Coefficients Weighted by Forest Land Area Data from RPA

Region	Forest Type	A	B	C	D
Cornbelt	Hardwood	37.1	88.8	17.7	9.1
Cornbelt	Softwood	43.9	43.8	25-1	8.4
Great Plains	Hardwood	34.8	34.7	30.6	14.9
Great Plains	Softwood	43.9	87.3	24.1	24.1
Lake States	Hardwood	37.1	88.8	17.7	9.1
Lake States	Softwood	43.9	43.8	25-1	8.4
Northeast	Hardwood	37.1	88.8	17.7	9.1
Northeast	Softwood	43.9	43.8	25-1	8.4
Rocky Mountain	Hardwood	34.8	34.7	30.6	14.9
Rocky Mountain	Softwood	43.9	87.3	24.1	24.1
Pacific Southwest	Hardwood	34.8	34.7	30.6	14.9
Pacific Southwest	Softwood	43.9	87.3	24.1	24.1
Pacific Northwest West	Hardwood	53.9	44.3	29.5	16.0
Pacific Northwest East	Hardwood	53.9	44.3	29.5	16.0
South Central	Bottomland Hardwood	15-3	61.0	6.1	3.2
South Central	Natural Pine	20.4	27.1	12.2	3.8
South Central	Oak Pine	20.4	27.1	12.2	3.8
South Central	Planted Pine	20.4	27.1	12.2	3.8
South Central	Upland Hardwood	15-3	61.0	6.1	3.2
Southeast	Bottomland Hardwood	15-3	61.0	6.1	3.2
Southeast	Natural Pine	20.4	27.1	12.2	3.8
Southeast	Oak Pine	20.4	27.1	12.2	3.8
Southeast	Planted Pine	20.4	27.1	12.2	3.8
Southeast	Upland Hardwood	15-3	61.0	6.1	3.2
Southwest	Hardwood	34.8	34.7	30.6	14.9
Southwest	Softwood	43.9	87.3	24.1	24.1

Source: Author calculations using Smith and Heath (2002) and forest land area data from RPA (Miles, 2003).

As noted above, Smith and Heath's model definition of forest floor excludes coarse woody debris materials, that is, pieces of dead wood that are not attached to trees. This is large woody material fallen or cut and left form live and standing dead trees with a diameter of at least 7.5 cm (Smith, 2004). To account for effects of growth, mortality, disturbance, and decay of carbon in this material, coarse woody debris is assumed to be a fixed fraction of tree carbon. Published ratios of coarse woody debris carbon to live tree carbon reported in US EPA (2003) and weighted ratios for FASOMGHG regions/forest types using forest land area data reported by RPA (Miles, 2003). The weighted ratios used are reported in Table 13-6.

Table 13-6. Weighted Ratio of Coarse Woody Debris (CWD) to Live Tree Carbon (Percent)

FASOMGHG REGION	Softwood	Hardwood	Planted Pine	Natural Pine	Oak Pine	Douglas Fir	Bottomland Hardwood	Upland Hardwood	Other Softwoods
North East	12.3	11.2	NA	NA	NA	NA	NA	NA	NA
Lake States	14.1	10.8	NA	NA	NA	NA	NA	NA	NA
Corn Belt	14.1	10.8	NA	NA	NA	NA	NA	NA	NA
South East	NA	NA	23.9	23.9	17.3	NA	21.8	24.3	NA
South Central	NA	NA	18.6	18.6	17.3	NA	15.7	15.0	NA
Rocky Mountain	12.6	26.7	NA	NA	NA	NA	NA	NA	NA
Pacific Northwest-West	NA	3.9	NA	NA	NA	11.9	NA	NA	15.4
Pacific Northwest-East	14.8	3.9	NA	NA	NA	NA	NA	NA	NA
Pacific SW	13.0	11.4	NA	NA	NA	NA	NA	NA	NA

Source: Author calculations using EPA (2003) and forest land area data from RPA (Miles, 2003).

13.2.4 Soil

Soil carbon is the second-largest carbon pool of carbon. Treatment of soil carbon follows Birdsey (1996) and recent work by Heath, Birdsey, and Williams (2004). FASOMGHG, computes soil carbon profiles using soil carbon data over time from Birdsey (1996). The regression specifies soil carbon and a function of age (see equation 8). The variables and parameters are reported in Table 13-7. The results of these regressions for land transferring from crops or pasture to forest in Tables 13-7a and 13-7b.

$$C^{S} = (A + Bt + Ct^2) / U^C \quad [8]$$

Table 13-7. Soil Carbon Variables and Parameters

Symbol	Description	Units	Source
C^S	**Total Soil Carbon**	**Mg/ac**	**Regression equation calculate using data from Birdsey (1996)**
A	**Regression Intercept**	**1,000 lbs per ac**	**--**
B	**Regression Co-efficient for t**	**1,000 lbs per ac**	**--**
C	**Regression Co-efficient for t^2**	**1,000 lbs per ac**	**--**
t	**Age of Stand**	**Years**	**--**
U^C	**Units conversion factor**	**1,000 lbs per acre = 2.205 Mg/ac**	**--**

Table 13-7a. Soil Carbon Profile for Land Moving From Crops to Forestry by Region: Regressions Based On Birdsey (1996) (1,000 lbs/ac)

Region	Forest Type	Intercept (A)	t (B)	t2 (C)
Southeast	Planted Pine	32.2	0.827	-0.004
Southcentral	Planted Pine	31.6	0.810	-0.004
Northeast	White-red-jack-pine, Spruce- Fir	68.5	1.473	-0.005
Lake States	White-red-jack-pine, Spruce- Fir	55.0	1.220	-0.005
Central States	White-red-jack-pine, Oak-Hickory	35-2	0.770	-0.003
Rocky Mountain	Planted Pine	34.2	0.754	-0.003
Pacific	Planted Pine, Douglas-Fir	41.4	0.897	-0.003

Table 13-7b. Soil Carbon Profile for Land Moving From Pasture to Forestry by Region: Regressions Based On Birdsey (1996) (1,000 lbs/ac)

Region	Forest Type	Intercept (A)	t (B)	t2 (C)
Southeast	Planted Pine	45.0	0.626	-0.003
Southcentral	Planted Pine	44.0	0.610	-0.003
Northeast	White-red-jack-pine, Spruce-Fir	93.9	1.159	-0.005
Lake States	White-red-jack-pine, Spruce-Fir	75.8	0.938	-0.004
Central States	White-red-jack-pine, Oak-Hickory	48.5	0.586	-0.002
Rocky Mountain	Planted Pine	46.7	0.600	-0.003
Pacific	Planted Pine, Douglas-Fir	56.7	0.696	-0.003

As Heath, et al (2004) note, little change in soil carbon occurs if forests are regenerated immediately after harvest. As a result, FASOMGHG assumes soil carbon on a reforested stand remains at a steady-state value. Currently, the age that this value is reached is assumed to be the minimum harvest age for FASOMGHG region/forest type (see Chapter X). This assumption is generally consistent with the ages at which steady-state levels of soil carbon are achieved in Birdsey (Birdsey, 1996).

$$C^{S} = A + Age_{min} + Age_{min}{}^{2} \quad [9a]$$

For example, a reforested softwood stand in the southeast with a minimum harvest age of 50 years would have a soil carbon value of :

$C^{S} = [32.2 + 50 \times (0.827) + 50^2 \times (-0.004)]/2.205 = (32.2 + 41.4 -- 10)/2.205 = 28.8$ Mg/ac [9b]

Afforested land coming from crop or pasture use start with the initial soil carbon value reported by Century -- -- -- and begin accumulating soil carbon until a steady-state is attained (again assumed to be the minimum harvest age for the FASOMGHG region/forest type). The soil carbon profile for an afforested stand use the regression coefficients in Tables 13a and 13b:

C^S = Century Ag Soil Carbon Value $\times ((B/A)t + (B/A)t^2,)$

Using this approach, FASOMGHG soil carbon values are consistent with the levels of soil carbon existing at the time of land use conversion and rates of soil carbon accumulation reported by Birdsey (1996).

13.3 Carbon disposition after harvest

This section describes how FASOMGHG physically tracks the fate of carbon, after harvest. Figure 13-4 provides a schematic of the disposition of carbon after harvest and points on the critical path are described. To calculate carbon in harvested logs, cubic feet of roundwood (the units in which timber is quantified in the model) is converted into metric tons of carbon using factors reported in Skog and Nicholson (2000) (see Table 13-10). These factors vary by region and are reported for logs coming from an aggregate softwood and hardwood stand. They exclude carbon in logging residue left onsite. Logging residue is tracked separately in the forest floor carbon pool described above in Section 9.1.2.3.

Harvested logs removed from site are converted into three types of outputs through primary manufacturing processes: FASOMGHG wood and paper products, mill residue, and fuel wood. The fate of each of these types is discussed in turn below.

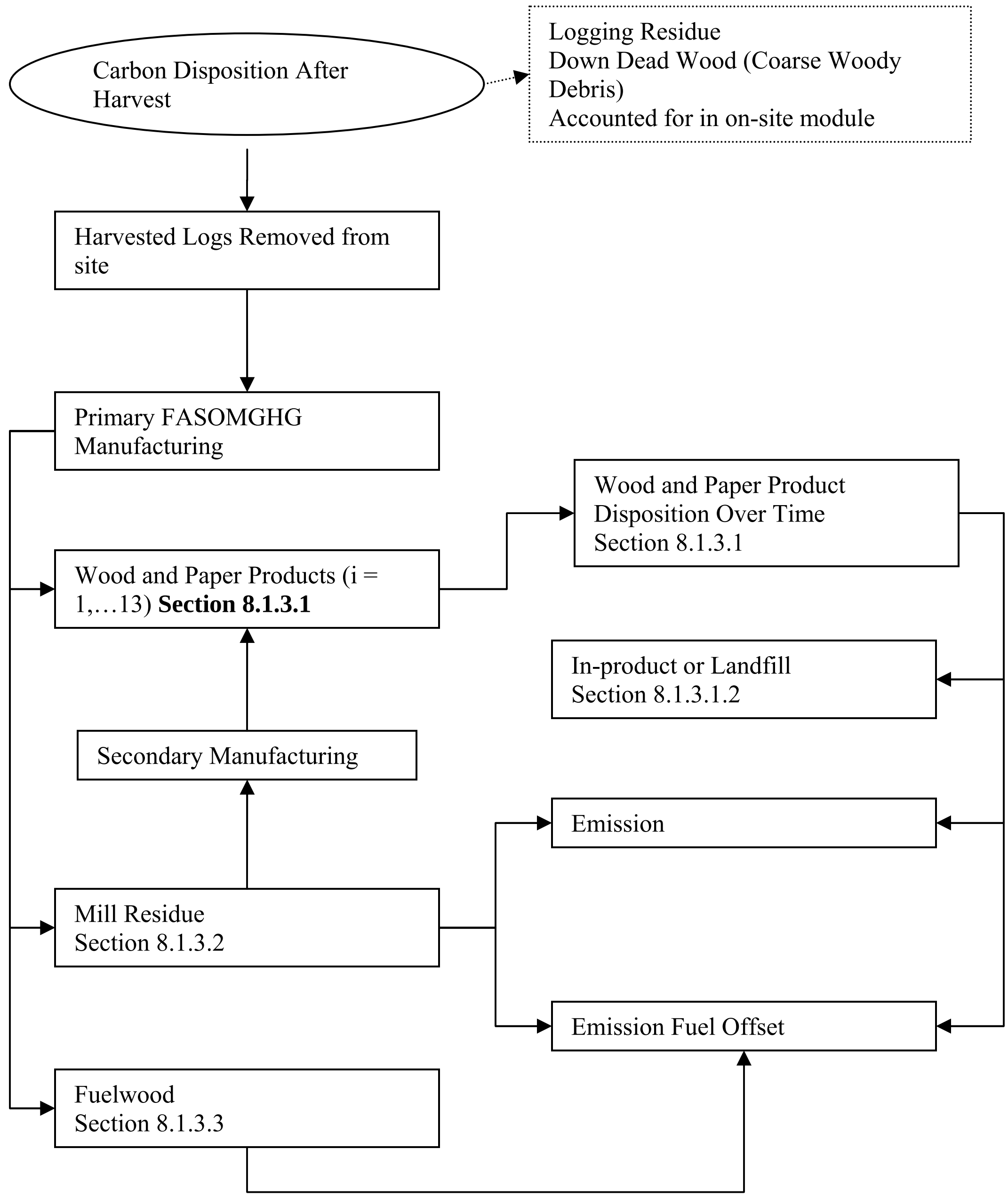
Table 13-8. Carbon per unit of Roundwood, by Region (lbs/ft^3)

Skog and Nicholson Region	FASOMGHG Region	Softwood Log	Hardwood Log
North East	North East	12.15	19.21
North Central	Lake States	12.55	17.33
North Central	Corn Belt	12.55	17.33
South East	South East	16.90	19.82

South Central	South Central	16.90	19.82
Rocky Mountain (Average of North and South)	Rocky Mountain	13.36	11.87
Pacific North West-west	Pacific North West-west	15-11	11.76
Pacific North West-east	Pacific North West-east	13.29	11.76
Pacific Southwest	Pacific Southwest	15-11	11.76

Source: Skog and Nicholson. 2000, Table 5-1.

Figure 13-4. Carbon Disposition after Harvest



13.3.1 Wood and Paper Products

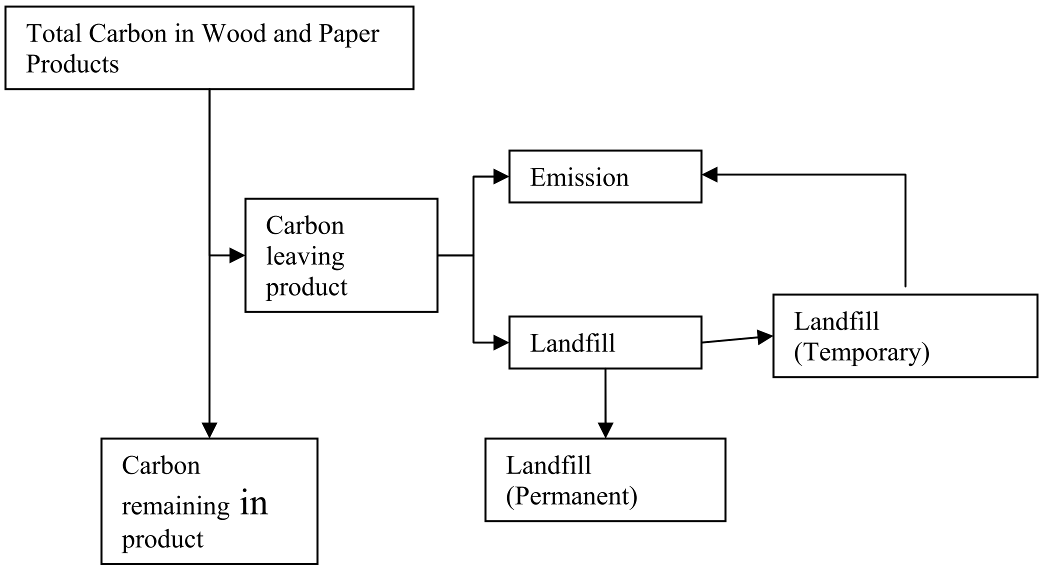
FASOMGHG contains the following 13 wood and paper products:

Softwood sawlogs for export,

Hardwood sawlogs for export,
Softwood lumber,
Softwood plywood,
Oriented strand board,
Hardwood lumber,
Hardwood plywood,
Softwood miscellaneous products,
Hardwood miscellaneous products,
Softwood used in non-OSB reconstituted panel,
Hardwood used in non-OSB reconstituted panel,
Softwood pulpwood, and
Hardwood pulpwood.

The previous FASOMGHG model handled product and other offsite carbon pools using a method developed in the early 1990s by Row and Phelps (Row and Phelps, 1991). The USFS has since modified their approach to product accounting using the work of Skog and Nicholson (2000). The distribution of product carbon changes over time and FASOMGHG tracks the fate of product carbon for each end-use using two pools: carbon remaining in-product and carbon leaving the product (see Figure 13-5). Carbon that leaves the product ultimately makes its way to emissions or is permanently sequestered in landfills.

Figure 13-5. Wood and Paper Product Carbon Disposition



13.3.1.1 Fraction Remaining in Product

Skog and Nicholson's model (2000) specifies a half-life values for a set of end-use categories (see Table 13-8). The half life represents the time it takes for approximately half of the product to decompose. For example, carbon store in paper products have a short life with 50 percent of carbon decomposing in 2 years. In order to map these end uses to FASOMGHG wood and paper products and compute the appropriate weighted half-life, FASOMGHG uses the end use weights reported in Table 13-10. For example, softwood pulpwood is only used in paper end uses (weight=1.0). Therefore the half life for this FASOMGHG product is 2 years.

Table 13-10. Distribution of FASOMGHG Wood and Paper Products Across End-Uses (Percent)

	FASOMGHG Product												
Skog End Use Categories	Softwood Sawlogs for Export	Hardwood Sawlogs for Export	Softwood Lumber	Softwood Plywood	Oriented Strand Board	Hardwood Lumber	Hardwood Plywood	Softwood Miscellaneous Products	Hardwood Miscellaneous Products	Softwood Used in Non-OSB Reconstituted Panel	Hardwood Used in Non-OSB Reconstituted Panel	Softwood Pulpwood	Hardwood Pulpwood
New Residential Construction													
Single family	0.33	0.04	0.33	0.33	0.58	0.04	0.13	0.33	0.04	0.13	0.13	0.00	0.00
Multifamily	0.03	0.00	0.03	0.03	0.05	0.00	0.02	0.03	0.00	0.02	0.02	0.00	0.00
Mobile homes	0.04	0.00	0.04	0.04	0.06	0.00	0.04	0.04	0.00	0.04	0.04	0.00	0.00
Residential upkeep & improvement	0.25	0.04	0.25	0.24	0.16	0.04	0.11	0.25	0.04	0.11	0.11	0.00	0.00
New Nonresidential Construction													
All except railroads	0.08	0.03	0.08	0.09	0.07	0.03	0.05	0.08	0.03	0.05	0.05	0.00	0.00
Railroad ties	0.00	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Railcar repair	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Manufacturing													
Household furniture	0.02	0.24	0.02	0.05	0.00	0.24	0.14	0.02	0.24	0.14	0.14	0.00	0.00
Commercial furniture	0.00	0.05	0.00	0.05	0.01	0.05	0.22	0.00	0.05	0.22	0.22	0.00	0.00
Other manufactured	0.04	0.10	0.04	0.08	0.02	0.10	0.09	0.04	0.10	0.09	0.09	0.00	0.00
Shipping													
Wooden containers	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Pallets	0.04	0.35	0.04	0.03	0.00	0.35	0.00	0.04	0.35	0.00	0.00	0.00	0.00
Dunnage etc.	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Other	0.13	0.01	0.13	0.01	0.04	0.01	0.14	0.13	0.01	0.14	0.14	0.00	0.00
Exports	0.03	0.08	0.03	0.04	0.01	0.08	0.05	0.03	0.08	0.05	0.05	0.00	0.00
Paper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 13-9. Half Life for Products in End Uses

End Use or Product	Half Life in Years
Paper	2
New residential construction	
Single family	100
Multifamily	70
Mobile homes	12
Residential upkeep & improvement	30
New nonresidential construction	
All ex. railroads	67
Railroad ties	12
Railcar repair	12
Manufacturing	
Household furniture	30
Commercial furniture	30
Other products	12
Shipping	
Wooden containers	6
Pallets	6
Dunnage etc.	6
Other uses for lumber and panels	12
Uses for other industrial timber products	12
Exports	12

To compute the fraction of carbon remaining in one unit of FASOMGHG products, the HWP model uses the data on the distribution of product across end-uses (Table 13-8), and an exponential decay function:

$$F^P = \sum [S_i F^P_{t-1} \times \exp^{(-\ln(2)/HL \times t)}] \quad [10]$$

The variables in this equation are defined in Table 13-11.

Table 13-11. Product Carbon Parameters

Symbol	Description	Units	Source
F^P	Fraction of Carbon remaining in-product for one unit of FASOMGHG product.	Percent	Calculated
S_i	Share of product in end use i.		Table 9
F^P_{t-1}	Fraction of carbon remaining in-product from the previous period	Percent	--

HL	End-Use Half Life	Years	See Table 8
T	Time	Years	

13.3.1.2 Fate of Carbon Leaving Wood and Paper Products

Carbon leaving the product pool moves to either the emissions pool or landfill pool. Skog and Nicholson's HWP model (2000) assumes that 67 percent of carbon leaving the wood product pool goes to landfills. Similarly 34 percent of carbon leaving the paper product pool goes to landfills. The remaining shares for each product are immediately released back to the atmosphere (emissions)

Once in landfills, the HWP model tracks carbon using permanent and temporary landfill pools. Carbon in permanent landfills is not released back to the atmosphere and remains sequestered in landfills forever. Carbon in temporary landfills decays and is eventually released to the atmosphere. The HWP model assumes approximately 77 percent of the wood product going into landfills remains permanently sequestered. Only 44 percent of paper product remains permanently sequestered. Finally, carbon in temporary landfills eventually is released to the atmosphere. The HWP model uses an exponential decay function for the degradable fraction landfill carbon and specifies a half-life value of 14 years for wood and paper products.

13.3.2 Disposition of Mill Residue

FASOMGHG also tracks the fate of mill residue using two pools: Mill residue used as an intermediate input for wood and paper products and burned at the mill (see Figure 13-6). Carbon in mill residues that make it to product are tracked using the appropriate product carbon profile described above. Residue used for other uses is tracked in the following manner. First, the fraction of other mill residue that is used for fuel is computed using data from Table 41 of the Forest Resources of the US, 1997 (Smith, et al, 1997). These fractions are reported in Table 13-12. Currently 1/3 of burned mill residue is used to offset fossil fuels. Currently, each unit of mill residue burned for energy purposes is assumed to get one unit of carbon offset credit. The model parameters can be modified to *not* assign a credit for residue burning for energy production.

Table 13-12. Fraction of Mill Residue Burned

Softwood	Percent

Northeast	40%
Lake States	75%
Corn Belt	75%
Southcentral	81%
Southeast	75%
Rocky Mountain	79%
Pacific Northwest-West	97%
Pacific Northwest-East	97%
Pacific Southwest	85%
Hardwood	
Northeast	44%
Lake States	56%
Corn Belt	56%
Southcentral	76%
Southeast	82%
Rocky Mountain	19%
Pacific Northwest-West	78%
Pacific Northwest-East	78%
Pacific Southwest	100%

Figure 13-6. Disposition of Carbon in Mill Residue

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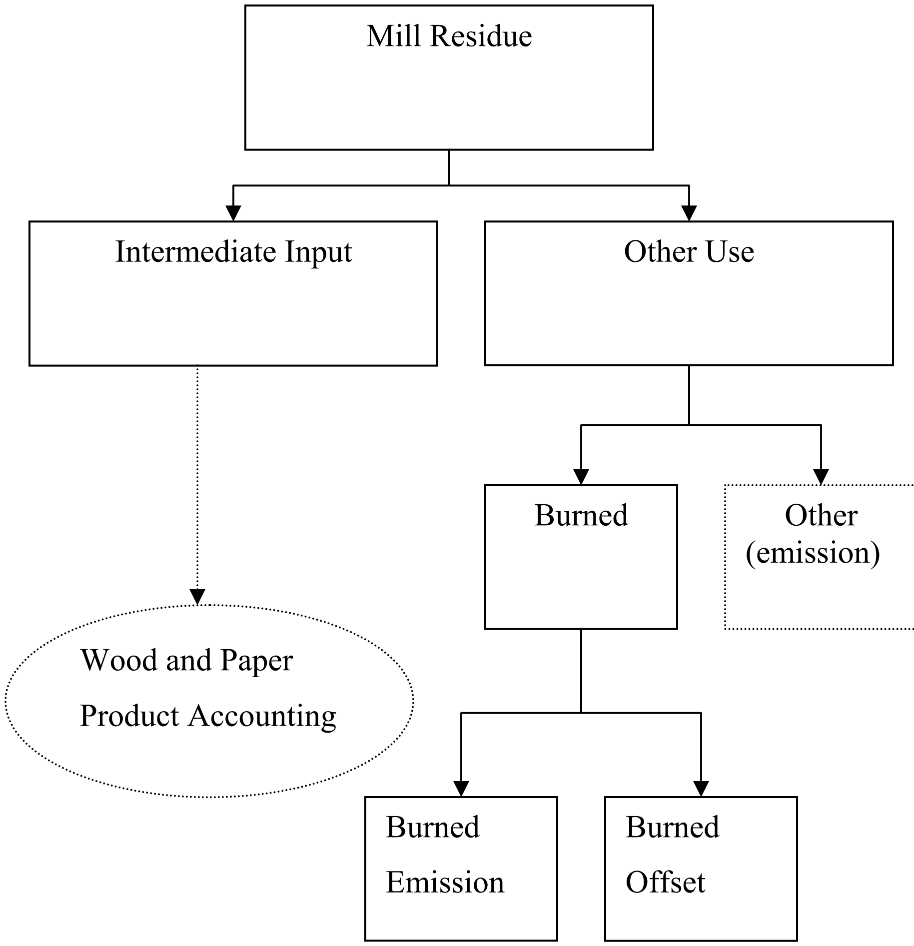

13.3.3 Disposition of Fuelwood

Harvested fuel logs and the associated carbon are used as to produce energy at mills (see Figure 13-7). The default assumption holds that 100 percent of fuel wood burned in the sawtimber and pulpwood production process are used to offset fossil fuels. The assumption can be modified down as far as zero percent at the discretion of the model scenario.

Figure 13-7. Disposition of Carbon in Fuelwood

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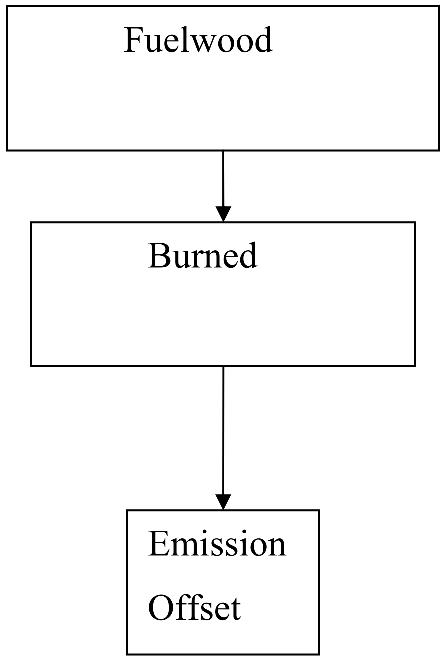


13.4 Disposition of Site Carbon after Deforestation

In FASOMGHG, land used in forestry can move to agriculture or developed use.

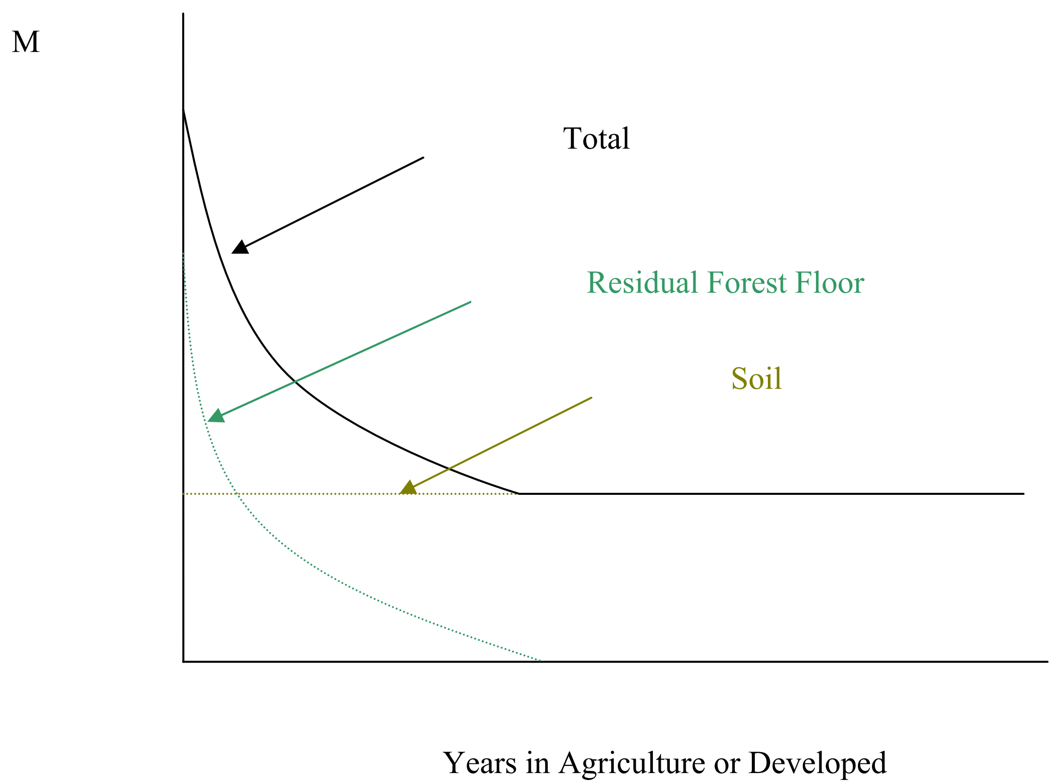
When land moves from forestry one of these uses, three carbon pools are tracked (see Figure 13-8):

Residual forest floor carbon
Soil Carbon in agriculture
Soil Carbon in developed use

For agriculture and developed land uses, the path of residual forest floor carbon stock is assumed to be the same as for the forest floor carbon profile after a harvest (see Eq [7]) above. This model of decay is based on the average forest floor of mature forests and regional averages for decay rates as described in Smith and Heath (2002).

Absent better date for transition paths of soil carbon, the following approaches are used. For forestry switching to agriculture, soil carbon levels are assumed to be consistent with century ag soil data and do not vary over time. For forestry switching to developed land use, we assume the soil carbon levels are consistent with the steady-state value of the minimum harvest age and use the data in Tables 13a and 13b to derive the soil carbon level this level does not vary with time.

Figure 13-8. Disposition of Site Carbon after Deforestation



14 CHAPTER 14 FOREST SECTOR DATA DETAIL (ADAMS AND ALIG)

The forest sector of FASOMGHG is patterned in large part after the basic structures of the TAMM, NAPAP, ATLAS, and AREACHANGE models. Data for the various demand and supply processes in the sector come primarily from the most recent versions of these models as described by Haynes (2003) for the U. S. Forest Service's 2000 RPA Timber Assessment and from forest inventory data collected by the Forest Service's Forest Inventory and Analysis groups.This chapter describes forest sector key models and data sources. Terms are defined in a Glossary in the Appendix.

Modeling of timberland dynamics in the forest sector component of the FASOMGHG model is based largely on the USDA Forest Service modeling system for conducting national periodic assessments of the nation's forests and related renewable resources under the Resources Planning Act (RPA) (Haynes 2003). Data for the different components are derived primarily from the 2000 RPA Timber Assessment. Next, we describe key models and data sources below. For more information on the RPA modeling framework see Haynes (2003).

The general modeling framework used for the 2000 RPA Timber Assessment has evolved over the past 20 years to fill needs for greater geographic and product specificity in the timber resource projections and now consists of a set of linked submodels. The Timber Assessment Market Model (TAMM) embraces the solid wood products sector and also provides the linkage between product markets (solid wood and pulpwood) and the timber inventory (Adams and Haynes 1996). The North American Pulp and Paper Model (NAPAP) is a model of the paper and board sector, with detailed treatment of fiber supply (recycled, roundwood, and short-rotation woody crops) (Ince 1999). The Aggregate Timberland Assessment System (ATLAS) is a structure for projecting timber inventory over time (Mills and Kincaid 1992). The AREACHANGE model explains the shifting of land between forest and non-forest uses and among forest types (Alig et al. 1990, Alig et al. 2003).

14.1 Changes in Timberland Area

14.1.1 Timberland Inventory Representation

Timberland by region in the FASOMGHG model is represented by aggregates, based on combinations of strata presented in Table 14.2.1.1. The sources and format of associated data representing timberland strata are discussed next.

To provide perspective, 358 million acres of private timberland existed in the US in 1997 (table 14.2.1.1-2) (Smith et al. 2001). One-half of the private timberland acres are in the South.

In addition, 80 percent of the private timberland area is held by nonindustrial private forest (NIPF)owners, although a large percentage of forest land in the Pacific Northwest is owned by the forest industry (see glossary for definitions). The area of National Forest timberland in the contiguous 48 states is 93 million acres, while other public timberland covers another 41 million acres. Finally, hardwood species are the predominant forest species group in the East while softwood species are the primary forest species group in the West.

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The RPA system of models is an example of a bioeconomic model, as it combines representations of both biological and economic processes. Major links among the models have evolved over time, and the modular structure facilitated development of a forest sector foundation for the FASOMGHG model. For example, timber harvest estimates lead to adjustments in timber inventories, given changes in forest growth and timberland area. Such adjustments in the FASOMGHG model are based on perfect foresight and economic optimality conditions, but draw upon very similar input data sets for initial inventory estimates and timber growth and yield. In ATLAS modeling, allocation of acres to MICs is exogenous or pre-set, governed in part by externally developed scenarios of prospective future private and National Forest timber management decisions. In the FASOMGHG model, allocation of acres in the future to MICs is endogenous, sensitive to market elements such as prices and costs. This background can be useful to bear in mind when viewing output from the respective forest sector modeling systems. Below we describe related RPA models and supporting data by the modeling categories used in Section 7.1.

The 504 million acres of US timberland contain almost one trillion cubic feet of timber (Smith et al. 2001). About half of that growing stock volume is on private timberlands (table 14.2.1.1-2). The majority of private timberland is within the eastern US, with most of that in the South. The Eastern regions have much more private timberland area and timber volume in the younger age classes. For example, 22% of timberland area in the East has stands with trees less than 20 years of age, in contrast to 12% for the West (Smith et al. 2001, Alig 2005). Timberland is managed differently by ownership, and the Western regions in the FASOMGHG model contain relatively more public timberland, 65% compared to 15% in the East.

The majority of public timberland is located in the Pacific Northwest and Rocky Mountain regions. The RM region has 48 million acres of timberland, more than twice as much as the Pacific Northwest region. However, timber volumes per acre are typically higher in the more productive Pacific Northwest, with its timber volume of 155 billion cubic feet exceeding that for the Rocky Mountain region (140 billion cubic feet).

Timberland on various public ownerships—including Federal, state, and local public owners—represented 29% of the US timberland and provided 11% of US timber removals in 1997 (Smith et al. 2001). Timber inventories on National Forests are represented in the current model but timber management and harvest decisions are exogenous or pre-selected. Representation of the timber inventory facilitates carbon accounting on the National Forest timberland. Timber inventories on other public timberlands are currently not represented but their timber harvests are taken as exogenous.[5]

Nontimberland, forestland constitutes about 30% of the forest land in the US. These lands include some withdrawn from timber harvest activities (e.g., wilderness) and low productivity lands (e.g., pinyon-juniper lands). Such forestland is stocked with at least 10% forest cover (see Glossary). Also included are forest areas adjacent to urban and built up lands. Although the land area in this category is large, data pertaining to site quality and inventory structure are generally

[5] National Forest timberland inventories are drawn from the RPA Assessment process and it is anticipated that consistent data for other public inventories will be ready in the near future.

unavailable. Thus, timber harvest on this land is taken as exogenous, and changes in forest inventory volumes or structure are not accounted for in the FASOMGHG model.

Timberland described above represents about four-fifths of forest land in the contiguous 48 states. Forest land is any land with at least 10 percent tree cover and timberland is that subset of forest land that has the capability to grow at least 20 cubic feet per acre per year of commercial timber products and is not legally withdrawn from timber harvest activities (see glossary in Appendix). Inventory information for non-timberland forest land, which is largely in public ownership, is not as complete as for timberland, and this precludes developing a comparable inventory (e.g., site class and inventory structure) of such lands in the FASOMGHG model. Such forest land contains a considerable amount of designated wilderness and low productivity land (e.g., pinyon-juniper), so that their exclusion represents a small part of commodity production. The expected direction of future policies will also likely place increasing weight on the management of such lands for non-market benefits. Next, we summarize how timberland is stratified in the FASMGHG modeling.

Each ***region*** in FASOMGHG possesses a different endowment of land and timber yields. Nine regions are used to represent the productive land base in the forest and agriculture sectors: Northeast, Lake States, Corn Belt, Southeast, South Central, Rocky Mountains, Pacific Northwest Westside, Pacific Northwest Eastside, and Pacific Southwest (Adams et al. 1996) (see earlier figure 3.10). Two additional regions that contain insignificant timberland areas (from a national perspective) fill out the agriculture side: the Northern and Southern Great Plains.

The stratum for land suitability was added beyond what was used in the ATLAS modeling. To enable the modeling of land exchanges, five **land suitability** classes were defined: FORONLY, FORCROP, FORPAST, CROPFOR, and PASTFOR. For the land use suitability classification, referred to as LAND CLASS in subsequent discussion, we used classes for crop or pasture plus a "forest only" class that can not shift use. On the agricultural side, acres by region that could potentially be converted from crop or pasture land to forest land were included in the CROPFOR and PASTFOR land classes, respectively, based on National Resource Inventory data of the USDA Natural Resources Conservation Service (1989, 2001) and the study by Moulton and Richards (1990). In the forestry inventory, acres that could be converted from forest to crop or pasture use were included in the FORCROP and FORPAST classes, respectively. Acres suitable for transferring between agriculture and forestry use were assigned to high and medium site classes. All other private timberland acres, which were not eligible for transferring between sectors, were assigned to the FORONLY land class.

Definitions of the private ***owner*** groups are the traditional ones, where industrial owners are integrated in some way to processing facilities and NIPF owners are not. Native American lands are included in the latter group.[6] National Forest inventory is represented, but public timber harvests from those lands and other public lands (e.g., State timberlands) are treated as exogenous. Timberland on the other public ownership (e.g., State timberlands) is not included, although their harvest levels are exogenous inputs based on a policy input.

Two or more ***forest type*** groups by region are used to reflect variations in timber yields, financial returns, and other attributes (e.g., forest carbon). In all regions except the SC, SE, and PNWW, two broad forest types-softwoods (SOFT) and hardwoods (HARD)-are used. In the Southern regions, five forest types were drawn directly from the 2000 RPA Timber Assessment (Haynes 2003): planted pine, natural pine, oak-pine, upland hardwood, and bottomland hardwood. For the Pacific Northwest Westside, the three forest types are Douglas-fir, other softwoods, and hardwoods.

FASOMGHG employs four different species types in all regions except the SC, SE, and PNWW: 1) SOFTSOFT -- softwood forest type in current and subsequent model periods; 2) HARDHARD -- hardwood forest type in current and subsequent model periods; 3) HARDSOFT -- hardwood forest type that is naturally regenerated or replanted to softwood type; and 4) SOFTHARD -- softwood forest type that is regenerated or replanted to hardwood type.

In the South, 25 forest type classes are used, based on combinations of the following five forest types reported by FIA (Smith et al. 2001): planted pine, naturally-regenerated pine, oak-pine, upland hardwoods, and bottomland hardwoods. An example is upland hardwoods-planted pine, where planted pine exists in the current model period after following upland hardwoods that covered an aggregate in the preceding model time period. Some forest type combinations or pathways are excluded, such as upland hardwood-bottomland hardwoods because of site considerations (table 14.2.1.1-3). For afforestation opportunities, table 14.2.1.1-4 lists forest types by region. **I THOUGHT WE DROPPED THIS**

In the Pacific Northwest Westside, nine forest type classes are used for existing and regenerated stands, based on combinations of the following three forest types: Douglas-fir, other softwoods, and hardwoods. An example forest type class is Hardwoods-Douglas-fir, where

[6] Native American timberlands were included with the "other public" ownership in the ATLAS modeling in the 2000 RPA Timber Assessment. Thus, comparisons of timberland areas and timber volumes by ownerships reflect such differences.

Douglas-fir exists in the current model period after following hardwoods that covered the aggregate in the preceding model time period.

The ***site productivity*** classification scheme is based on potential annual cubic-foot volume growth at culmination of mean annual increment in fully stocked natural stands (Haynes 2003). Inventory data allowed differentiation of timberlands into three site classes (low, medium, and high) in the two southern regions and the Pacific Northwest Westside. Elsewhere, limited data only allowed identifying a single average site class.

Timber yields can vary markedly by site groups. For the three site classes in the SC, SE, and PNWW, measures of forest productivity are: 1) HIGH -- High site productivity group (as defined in ATLAS); 2) MEDIUM -- Medium site productivity group; and 3) LOW -- low site productivity group. The site groups were defined based on ATLAS inputs from the 2000 RPA Timber Assessment (Haynes 2003). Productivity ranges can vary by region. For the South, the HIGH site group produced at least 85+ cubic feet/acre/year at culmination of MAI. The MEDIUM site group produced 50-84 cubic feet/acre/year while the LOW site group produced 20-49 cubic feet/acre/year. In the Pacific Northwest-Westside region, the site groups were defined for Hemlock and other species. For Hemlock, the HIGH site group can produce at least 225+ cubic feet/acre/year at culmination of MAI. The MEDIUM site group can produce 120-224 cubic feet/acre/year, while the LOW site group can produce 20-119 cubic feet/acre/year. For all other species, the HIGH site group produced at least 165+ cubic feet/acre/year; the MEDIUM site group 120-164 cubic feet/acre/year; and the LOW site group produced 20-119 cubic feet/acre/year.

An average or medium site class was assigned for National Forest timberland across regions and for private timberland in regions other than the Southeast, South Central, and Pacific Northwest Westside. An exception is use of an average or medium site class for bottomland and upland hardwood forest type groups in the Southern regions. **THE SITE PRODUCTIVITY GROUPS CAN'T VARY BY SPECIES!!!**

Five year **age cohorts** were developed for trees on timberland in the FASOMGHG model, based on ATLAS information and FIA estimates. Five year age classes were used by ATLAS for the two southern regions, and this facilitated assigning acres within ATLAS age classes to appropriate FASOMGHG age cohorts. ATLAS assignment of acres to age classes for the Southern regions included having the first year age cohort class represent years 0-7. Class 2 represents ages 8-12, class 3 represents 13-17 years of age and so on until the terminal cohort 18 that spans aggregates five years and older.

For the Pacific Northwest Westside, age cohorts are separated into 21 five year classes. Age cohort 1 (0-4 years of age) comprises the first class, 2 (5-9) comprises the second age class and so on until age cohort 21, which is comprised of aggregates aged 100 and older. In regions outside the SC, SE, and PNWW, ATLAS age classes are in ten-year intervals and start in year 1 (0-9) and continue with year 2 (10-19), and so on until age class 10 that contains aggregates 90 years and older. In these regions, the ten year age classes were separated into five year age cohorts to align with the Southern and Pacific Northwest Westside regions.

WHAT ABOUT REGIONS OUTSIDE THE PNWW AND SOUTH.

I THOUGHT WE WEREN'T GOING TO TALK ABOUT THE NF INVENTORIES SINCE THEY'RE NOT IN TH E MODEL???

~~Inventory acres of existing National Forest timberland from ATLAS were complied into FASOMGHG input tables in the same way as described above for private timberland. National Forest data from ATLAS modeling was also stratified the same as ATLAS private timberland data (Mills and Zhou 2003). Acres were classified by region, land class, owner, forest type, site class, MIC, and age cohort. Southern National Forest data were provided in five year increments, while areas outside the South were represented by ten-year age intervals. Forest types were aggregated into softwood and hardwood groups for all regions. Each stand in the inventory was assigned a medium site class, because no site detail is provided in ATLAS for National Forest timberland (Mills and Zhou 2003). National Forest inventory data were not broken out by land class, as timberland is assumed not to be eligible for conversion to other land uses.~~

14.1.2 Land Base Adjustments

Transfers of land between the agriculture and forest sectors are endogenous in the FASOMGHG model. Exogenous projections of the conversion of timberland and agricultural land to developed uses are drawn from modeling by Alig et al. (2004). Population and personal income are key drivers in the model (table 14.2.1.1-5).

The projections of conversions to urban and developed uses were drawn from a synthesis of findings from RPA-based land use studies, a study by Alig et al. (2003), and analysis of the 1997 National Resource Inventory (NRI) data. Because conversion and development of farmland, forests, and other open space accelerated during the 1990s, FASOMGHG estimates of deforestation were updated from statistical and econometric analyses of data by Alig et al. (2003). We also drew upon analyses of developed area trends and projections prepared by Plantinga and Lubowski as part of the 2005 RPA Assessment Update (Alig and Plantinga 2004), based on NRI data. In addition, we examined trend data for forest area compiled for the 2000 RPA Assessment by the USDA Forest Service.

For the contiguous United States, each developed area is designated by State, and is assumed to come out of existing FASOMGHG land suitability classes (e.g., FORCROP) in proportion to what exists currently. The proportion that each state contributed to total development in the contiguous United States was based on data from the National Resources Inventory by the USDA Natural Resources Conservation Service (2001). Deforested acres are assumed to exit the timberland base by age cohort in proportion to the existing distribution of total NIPF timberland area by age cohort.

Consistent with the early FASOM work (Adams et al. 1996), FASOMGHG projects no significant net change in timberland area for forest industry ownerships. By assumption, this means that the amount of NIPF timberland acquired by forest industry will offset the conversion of some forest industry land to urban and developed uses. Thus, developed land use movements in the modeling were restricted to NIPF owners.

Another exogenous land transfer into forestry is tree planting due to government programs. Tree planting due to government programs was enrolled each time period by region, for reforestation and afforestation. Estimates were based on RPA land base analyses (Alig et al. 2003), tree planting reports from the State and Private Forestry branch of the USDA Forest Service (1998), a study by Kline et al. (2002), and personal communication with State and Private Forestry staff. Historically, most of the government-subsidized US tree planting has been in the South, mainly involving pine plantations. For example, in 1998, about 80% of all US land planted in trees was in the South, represented by the Southeast and South Central regions in the FASOMGHG modeling (see figure 3.xx in earlier chapter).

14.2 Forest Inventory

Forest inventory data representing the private timberland base consists of the area by strata described earlier and the merchantable timber volume per acre. Each stratum is represented by the number of timberland acres and the growing stock timber volume per unit area (in cubic feet per acre) it contains. FASOMGHG inventory data were derived from the ATLAS inventory estimates for the 2000 RPA Assessment (Haynes 2003). The ATLAS data sets are based on approximately 180,000 permanent ground plots maintained by regional FIA units of the USDA Forest Service (Smith et al. 2001). Example FIA surveys for one State are the last periodic surveys for western Oregon (Azuma et al. 1997) and eastern Oregon (Azuma et al. 2002). More information on FIA surveys can be obtained from the national FIA Web site (http://fia.fs.fed.us), including description of its 76-year history as the nation's forest census dating back to the McSweeny/McNary Act of 1928. Over its history, FIA units have continuously monitored the extent, condition, and trends of our nation's forests, and in recent decades have played an important role in supporting the periodic RPA Assessment and by extension helping support the FASOMGHG modeling.

The timberland base in the FASOMGHG model consists of inventory area and timber volumes per acre for private ownerships and National Forests, based on compiled data from inventory plots maintained by regional FIA units of the USDA Forest Service (Smith et al. 2001). The FIA surveys conducted by the USDA Forest Service are designed to provide objective and scientifically credible information on key forest attributes, such as forest stocks, growth, harvest, and mortality. Related data are collected on region, forest ownership category (e.g., forest industry vs. nonindustrial private forests), and cover type (e.g., planted pine), by using a sample of around 180,000 permanent plots. The FIA inventories provide consistent forest inventory data for the Nation back to 1953 (Smith et al. 2001). The FIA inventories measure approximately one field plot for every 6,000 acres of forest land in most regions.

14.2.1 Even-aged Forest Inventory

A key determinant of what timber volumes will grow in the various timberland strata of the inventory are current and possible future timber management regimes, referred to here as timber management intensity classes (MICs). MICs representing regimes or packages of silvicultural practices now being used and those that might be applied to future stands were developed for the 2000 RPA Timber Assessment in collaboration with the American Forest and Paper Association, the Southern Forest Resources Assessment Consortium, and State Forestry agencies in different regions (Haynes 2003). MICs describe the methods of regeneration (natural or planted), stand density control (precommercial or commercial thinning), fertilization, and method of harvest (partial cutting or clearcutting). Another class is area reserved from harvest. The MICs represents a regional average response for a particular forest type and site class.

We use two broad representations of timber management: even-aged and partial cutting. In partial cutting, we remove typically only the mature trees, leaving the immature trees to grow, thereby allocating a portion of the growing space to regeneration. To contrast, we remove all of the trees when harvesting an even-aged stand in order to allocate all of the growing space to regeneration. For example, when growing southern pine plantations for timber, an even-aged management scheme is represented.

At its most basic level, ATLAS uses an “even-age” model of the timber inventory, in representing the inventory as a collection of age classes. ATLAS advances acres through the age classes over time to simulate the growth and progression of timberland aggregates. Throughout a projection, each unit of area, or cell, can be identified by attributes or strata. The projection mechanism in ATLAS moves each aggregate cell along an independent timber yield trajectory. The timber yield estimation process projects cell volumes period to period in a fashion consistent with the timberland inventory age classes. The timber yield tables and associated yield projection inputs required for the growth models were derived from FIA field data, from cooperative research and consultation with private forest land owners, and from previous studies (Haynes 2003). The FIA field data describe forest conditions at a plot level, which are aggregated to regional levels by strata to combine a broad mix of conditions. The even-aged characterization used by ATLAS gives way, in effect, to a multi-age model where age classes might alternatively be thought of as growth classes.

For the 2000 RPA Timber Assessment, the most detailed representation of the timberland inventory was for the key timber supply regions of the SC, SE, and PNWW. Examples of added detail for these regions are the site classes described above and the timber management intensity classes described in the next section. Timberland data in those two regions were further stratified by three site productivity classes and up to 12 timber management intensity classes (table 14.2.2.1). Thus, the most detailed set of timberland attributes used to identify a unit of private timberland inventory would be region, owner, forest type, site productivity class, management intensity classes, and age. Timber resource data for National Forests were stratified into three management intensity classes.

For all regions other than the SC, SE, and PNWW, the FASOMGHG model uses two MICs that dictate how timberland aggregates are managed: 1) passive -- lowest management intensity; and 2) low -- low management intensity class. The "passive" MIC refers to very little management intervention between harvests of naturally regenerated aggregates. The low MIC refers to custodial management of naturally regenerated aggregates, and may include protection measures such as fencing but no significant intermediate treatments such as fertilization or precommercial thinning.

The passive MIC was added in the FASOMGHG model beyond the ATLAS-based MICs to represent future harvested acres that are totally passively managed, where the owner accepts whatever type and rate of regeneration occurs naturally. Relative to the low MIC, where timberland receives a low-level of timber management, such as forest protection and elimination of grazing by livestock, future merchantable timber yields for the passive MIC are lagged ten years.

Allocation of the existing or initial timberland inventory by MIC in the FASOMGHG model is based on the ATLAS distribution by region, owner, forest type group, and site class. The ATLAS information in the 2000 RPA Timber Assessment was updated in collaboration with the American Forest and Paper Association, State Foresters (Moffat et al. 1998), and the Southern Forest Resources Assessment Consortium (Haynes 2003). In the South, forest industry surveys for the RPA Timber Assessment were compiled by the American Forest and Paper Association, while the responses from State Foresters were compiled at North Carolina State University (Moffat et al. 1998). A similar process was used in the West for forest industry lands (Adams et al. 1992).

For the SC, SE, and PNWW in the FASOMGHG model, an expanded set of MICs is modeled. The southern MICs are drawn from the ATLAS-based ones, in some cases involving combining or collapsing into the fewer number of FASOMGHG ones. In the Pacific Northwest-Westside, the MICs were based on studies by Adams et al. (1992, 2002), supplemented by current literature and expert opinion. Specific treatment regimes (e.g., timing of intermediate treatment) were assigned to each individual MIC using the same sources from which MICs were derived. In the Southeast and South Central regions, Siry's study (1998) was used to determine timing of planted pine treatments, including such treatments as commercial thinning and fertilization. Herbicide treatment in these scenarios was assumed to be conducted with fertilization at time of thinning. Timings of pre-commercial thinning and partial cuts were obtained from Mills (2003). For treatment information for short-rotation planted pine, information was obtained from the study by Siry (2002). Prescribed burning timing and treatment practices were estimated from Devos (1999). The Pacific Northwest-Westside treatment regime was developed using information from Adams et al. (2002) and the Oregon Department of Forestry's 1998 surveys of management regime activities applied by industrial and non-industrial private forest landowners.

Ten MICs were developed for the Southern regions, with the most for pine plantations (table 14.2.2.1). Representative MICs from ATLAS were chosen based on their relative amount of acres in production and estimated future production. The MICs for the Southeast and South Central regions are identical with respect to treatment prescriptions. To further validate the selected planted pine MICs, given planted pines' relative importance in timber production in the South, the ability for each MIC to generate positive returns was evaluated. Each planted pine MIC did produce positive net present values across the South (Siry 2002).

Six MICs were developed for the Douglas-fir forest type group in the Pacific Northwest Westside region (table 14.2.2.1), expanded beyond what was simulated in the first-generation FASOMGHG model for this important timber producing region. The MICs incorporate two types of regeneration (natural, planting), commercial and pre-commercial thinning, and fertilization.

All afforested land in the FASOMGHG model is represented by even-aged timber management. For afforested land in regions other than the South, such afforestation aggregates can be managed using a low MIC, where agricultural lands revert to naturally-regenerated softwood timberland. After forest establishment, the timberland is managed in a low intensity manner, similar to that for the low MIC for regenerated timberland in the region.

In the South, active afforestation is simulated. Agricultural lands are planted to pines and can then be managed using one of two MICs: medium afforestation management, for minimal management before timber harvest in planted aggregates under even-aged management; and high—beyond the medium level, this involves use of genetically improved stock, fertilization and/or other intermediate stand treatments.

The South and Corn Belt are the only two regions having afforested hardwood aggregates. In the South, bottomland hardwood planting options in the Southeast and South Central regions follow from recent emphasis on bottomland hardwood restoration (Amacher et al. 1997; Huang et al. 2003; Shabman and Zepp 2000; Stranturf et al. 2000). Hardwood afforestation opportunities also appear significant in the Corn Belt, with the relatively productive land. For other regions, active hardwood afforestation is not simulated because of a lack of significant amount of historic hardwood planting.

Treatments for afforested bottomland hardwoods were derived from the literature (Amacher et al. 1997). Information on specific treatments for the bottomland hardwood afforestation was limited, especially regarding individual silvicultural treatments and timing within an MIC. Amacher et al. (1997) point out there is no current published work that establishes the financial feasibility of thinning bottomland hardwood stands. Based on this information, only intermediate treatments of herbicide and fertilizer were included in the afforestation of bottomland hardwoods.

14.2.2 Partial cutting Intensity Classes

An advance beyond the first-generation modeling of the forest sector in the FASOMGHG model (Adams et al. 1996) is the introduction of partial cutting representation of timber management for selected regions. Partial cutting MICs on private timberland are modeled in the Southern and Pacific Northwest Westside regions. A partial cutting MIC is used in all regions for the modeling of National Forest inventory. In partial cutting, we remove typically only the mature trees, leaving the immature trees to grow, thereby allocating a portion of the growing space to regeneration. Such partial cutting in practice can arise from various landowner objectives and setting, including landowner adherence to traditional silvicultural practices recommended by forestry professionals, retaining greater structural diversity in the forest, avoiding reforestation requirements set by regulations, promoting aesthetic values, or other reasons. Thus, existing practices on the ground can involve variable retention harvests, and a mix of silvicultural systems and other approaches reflecting economic and operational constraints. Our broad representation of partial cutting timber management draws upon related modeling tested in the 2000 RPA Timber Assessment (Haynes 2003, Mills and Zhou 2003) and regional studies (e.g., Adams et al. 2002).

Partial cutting can take place in the Southern regions in forest types other than planted pine: natural pine, oak-pine, upland hardwood, and bottomland hardwood. This partial cutting timber management is described as low intensity selective harvest by Haynes (2003). More than 75 million acres of natural pine, oak-pine, bottomland hardwood, and upland hardwood in the South Central and Southeast are managed under partial cutting, based on representation in ATLAS modeling for the 2000 RPA Timber Assessment (Mills 2003). The MIC set in the FASMGHG model for the two southern regions includes three partial cut regimes: low, high, and high-plus (Alig et al. 2005). The high-plus partial cut MIC only applies to natural pine stands in the existing inventory, but can be applied to all four naturally-regenerated forest types concerning regenerated or "New" yield estimates.

Based on ATLAS harvesting patterns, partial cut activity was limited to four entries for an aggregate over the 100-year FASOMGHG projection horizon. This restricts existing stands that enter FASOMGHG at older ages in receiving only one or two partial cutting treatments before the 100-year mark. If existing aggregates persist beyond 90 years, they can be clearcut and regenerated back under multiple MIC options. This restriction is related to ATLAS aggregated partial cutting data, where activity ceases after approximately year 90. The timing of the initial harvest varies by site class (Alig et al. 2005).

In the Pacific Northwest Westside region, partial cutting MIC's on private timberland are used in the Douglas-fir and other softwoods forest types, with three MIC's: low, medium, and high. Natural regeneration for each partial cutting aggregate is simulated in these MICs. The initiation age and length of cutting intervals with growing stock removals for the low-MIC partial cutting varies with site class. As in the South, volume thresholds are used with the Forest Vegetation Simulator model (Crookston and Stage 1999, Crookston and Havis 2002; Stage 1973), based on observable volume patterns in the aggregated ATLAS partial cut information (Alig et al. 2005).

In the Pacific Northwest Westside, treatment of existing stands under the three partial cut MICs is the same as described in the regenerated projections, except that the age of existing stands is used as the harvest initiation criterion. Aggregates with low site index, for instance, will have partial cutting from above if the stand age is at least 35 and removal of 25% of the trees 7 inches dbh and higher will result in one thousand cubic feet of timber. For medium site index stands, a removal will occur if the aggregate age is 30, and for high site index stands age must be at least 25.

Partial cutting is also an option for National Forest timberland aggregates. National Forest timberland was allocated to three MICs in ATLAS, in a pre-set manner, and we applied that information in developing the corresponding input sets for the FASOMGHG model. The MICs include a low intensity one with no treatments, a low partial cut MIC, and a reserved MIC. Across the nine forest regions, two forest types (softwoods and hardwoods) are represented by these MICs. The regional inventories on National Forest timberlands were simulated using these MICs, but in contrast to private timberlands, the allocation of acres by MIC and timber harvest levels are pre-set or exogenous.

14.3 Timber growth and yield

The FASOMGHG model requires projected yields for existing aggregates, reforested aggregates, and afforested aggregates. Timber yields can vary markedly by MIC, as shown in the example in figure 14.2.3 for planted pine yields in the South.

14.3.1 Existing Aggregates of Private Timberland

Estimates of existing aggregate yields were obtained from the ATLAS model used for the 2000 RPA Timber Assessment (Haynes 2003, Mills and Zhou 2003), except for the Pacific Northwest Westside region (discussed below). The ATLAS model provides empirically-based yields per acre based on USDA Forest Service FIA plot data. Yields for each RPA region are presented by age class, forest type, site class, and management intensity class. Timber yields by site class and region were assumed to be equivalent for FORONLY, FORCROP, and FORPAST land suitability classes.

Under even-aged management, timber yields for existing and reforested stands in the low management intensity class were derived from ATLAS base yield tables. These cases involve use of ATLAS's "approach to normal" or relative density equations and regeneration stocking ratios as described by Mills and Kincaid (1992) and Mills and Zhou (2003). The base yields are based on a set of measurements from permanent FIA sample plots. Timber growth and yield parameters used in the ATLAS modeling are developed from the FIA data. The use of empirical growth rates embodies the effects of historical and recent management practices and disturbances, the latter including fire if it occurred. The ATLAS approach estimates net timber growth by age for each regional forest type. Timber yields are then an accumulation of net annual growth.

Commercial thinning volumes under even-aged timber management are part of some of the MICs in the Southeast, South Central, and Pacific Northwest Westside regions, in addition to final harvest volumes for aggregates under even-aged MICs. Commercial thinning yields are the commercial volumes removed from an aggregate in the intermediate period between forest establishment and final harvest. Commercial thinning yields are estimated for particular MICs in existing, regenerated, and afforested stands. Commercial thinning volumes for the Southeast and South Central regions are based on ATLAS modeling.

Timber yields for passively managed aggregates are lagged ten years relative to those for the corresponding low MIC group. In FASOMGHG, all timber yields are assumed to remain constant after 100 years. Stocking considerations also include "operational falldown," which took into account wind-damaged timber, breakage during harvesting, and other real-world factors.

Under partial cutting timber management, timber yields for the partial cut MICs in the South are based on ATLAS's approach (Mills 2003), where partial timber harvests remove a portion of the timber volume to mimic a forest stand subject to multiple harvest entries. Partially cut stands in the South were aggregated into the three partial cut regimes to estimate existing stand yields. Removals of growing stock in partial cutting MICs take place at scheduled intervals (Alig et al. 2005), with a certain percentage of an aggregate's volume removed each interval. Harvests can be delayed if total harvestable volume falls below a threshold merchantable level in any of these intervals (Alig et al. 2005). In that period, the stand is not harvested, and the stand is then harvested in the subsequent interval if the threshold criterion is met. Threshold timber harvest volumes by region were based on information from partial cutting activity totals in ATLAS. Thresholds are specified that define minimum amounts of harvestable growing stock volume by region before harvest is implemented.

For the Pacific Northwest Westside, the Forest Vegetation Simulator (FVS) (Stage 1973, Teck et al. 1997) was used to incorporate a recently completed FIA periodic survey for Western Washington, in estimating timber yields for existing and regenerated aggregates. FIA databases for western Oregon and western Washington were used to populate plot and tree list files required for projecting timber growth and yield with the FVS model (Alig et al. 2005). The FVS model allows more direct estimation of timber yields by sawtimber and pulpwood proportions, compared to the first-generation approach of obtaining (non-modeled) estimates from FIA sources (Adams et al. 1996). The FVS model follows the Prognosis Model developed in the 1970s and has been applied in a number of applications by others (e.g., Crookston and Stage 1999), and associated information or guidelines were drawn upon in developing yields that reflect current timber management and anticipated regeneration options.

FVS estimates of timber yields for existing stands are based on FIA data, used in input form as tree lists. Timber growth and yield projections are dependent on interactions between trees within stands. **The FIA samples of current growth or increment are used to project yields for existing stands, reflecting unique variations in site and environment not represented in the FVS parameters.** <<<<WHAT IS THIS????? Some or all of the following information is used, depending in part on the geographic variants of the FVS model (Crookston and Stage 1999): site conditions (e.g., site index, stand density index or basal area maximums, elevation), characteristics of each tree measured in the inventory (e.g., species, tree height, current diameter at breast height), and other information (e.g., tree history code, crown ratio). For example, species is used in FVS to index the various growth models.

14.3.2 New or regenerated aggregates of private timberland

New stands can result either from reforestation or regeneration of timberland, or from afforestation of agricultural land. Except for the Pacific Northwest Westside, estimation of regenerated yield estimates is based on similar ATLAS modeling or related studies, with adjustments for regeneration stocking assumptions. The initial volume for a regenerated stand in ATLAS is determined by the base timber yield table and an input parameter termed the regeneration stocking proportion (Mills and Kincaid 1992). This regeneration stocking proportion is assigned upon entry into the first or zero age class for an ATLAS aggregate, depending upon the region, owner, forest type, and site class combination. Timber stocking in subsequent periods (or age classes as the aggregate moves through time) is based on the stocking trajectory that the aggregate was assigned at time of regeneration.

For example, regenerated stands in the medium or high MICs and afforested stands were assumed to be fully stocked relative to either ATLAS or Birdsey (1996) reference or base yields. For low MIC timberland, new stands were modeled as stocked as a percentage of fully stocked, based on corresponding ATLAS estimates. Likewise, their timber yield estimates are based on use of ATLAS's relative density equations by region (Mills and Kincaid 1992). As with existing stands, timber yields for regenerated stands allocated to a passive MIC are lagged ten-years relative to those for the low MIC group (i.e., ten year relative regeneration lag).

For partial cut MICs in the South, regenerated yield tables were created using yield estimates from the counterpart ATLAS modeling, drawn from guidelines reported by Haynes (2003). Partial cut yields are estimated for the naturally-regenerated types: natural pine, oak-pine, bottomland hardwood, and upland hardwood.

For the Pacific Northwest Westside region, regenerated yields were obtained from the FVS model (Alig et al. 2005). Partial cut yields estimated by the FVS model for the Pacific Northwest Westside are based on similar interval and threshold volume guidelines as in the case of existing yields.

14.3.3 Afforested aggregates

Afforestation only occurs on NIPF land in the model, and can involve either tree planting or natural reversion of agricultural lands. For planted afforestation cases, resulting aggregates were assumed to be fully stocked. Regions likely to experience significant amounts of afforestation are based on estimates by Birdsey (1996) for planted pine, and by Amacher et al. 1997; Huang et al. 2003; Shabman and Zepp 2000; and Stranturf et al. 2000 for bottomland hardwood restoration trends. The mix of forest species within a region comprising a planted forest types was determined using Birdsey's (1996) estimates of forest types planted by state, national tree planting data (USDA Forest Service 1998) and expert opinion.

In the Southeast and South Central regions, planted pine afforestation yields were based on Birdsey's estimates (1996) for planted southern pines. These planted pine yields are represented in the medium and high FASOMGHG site classes for pasture and crop land, respectively.

Bottomland afforestation yields for the South Central region were derived using average yields for three forest type groups comprising afforested bottomland hardwoods (Murray et al. 2002) and timber yields from Murray's study (2003) for planted bottomland hardwoods.

Non-planted afforestation yields were derived from Birdsey (1996) and Moulton and Richards (1990). Birdsey gives yields (cubic feet per acre) by Moulton and Richards (1990) region and forest type for crop and pasture land. All afforested acres were assumed to be fully stocked in terms of ATLAS yield standards. Thus, yields were derived directly from Birdsey's yield tables for those regions in which only one species was planted. Weighted afforestation yields were derived for the Northeast and Pacific Southwest regions based on planting percentages by forest type given in Birdsey (1996) and tree planting statistics (USDA Forest Service 1998). Crop land planted to forest was assigned a high FASOMGHG site class while acres planted on pasture land were assigned a medium site class.

14.4 Harvest

As background, annual removals of growing stock on US timberland are approximately 16 billion cubic feet (Smith et al. 2001). The majority of this volume, 10 billion, comes from the Southern regions. The bulk of volume in these regions (95%) is harvested on private land. Of this, 69% comes from NIPF timberland. National Forests provided 5% of the annual harvest and all public land (including National Forest) makes up 10% of the national annual harvest (1.7 billion). In FASOMGHG, the public timber harvest is exogenous.

In FASOMGHG, harvest of an acre of timberland involves the simultaneous production of some mix of softwood and hardwood timber volume. In FASOMGHG, this is translated hardwood and softwood products (sawlogs, pulpwood, and fuelwood) that are described next.

Percentages of growing stock timber volumes are assigned to three product types -- sawlogs, pulpwood, and fuelwood, by softwoods and hardwoods. This results in six possible product classes: 1) SAWTSW -- Softwood sawtimber products; 2) PULPSW -- softwood pulpwood products; 3) FUELSW -- Softwood fuelwood products; 4) SAWTHW -- Hardwood sawtimber products; 5) PULPHW -- Hardwood pulpwood products; and 6) FUELHW -- Hardwood fuelwood products. The percentages of growing stock volume allocated to different products can vary by region, forest type, site class, MIC, and by age class. The estimates were obtained from the regional FIA units, with most based on analysis of available FIA data and expert opinions of analysts in each region.[7] For example, in the South, estimates were checked against similar product proportion tables (Siry 2003), and validated by Southern FIA personnel

[7] For the Pacific Northwest Westside, the Forest Vegetation Simulator provided estimates by size class that were useful for product characterization.

(Johnson 2003). For the West, Morgan (2003) provided expert opinions for some product proportions.

The product mix changes over time, as the stand ages, and between rotations if the management regime (intensity) changes. Downward substitution (use of a log "normally" destined for a higher valued product in a "normally" lower valued application) is allowed when the price spread between pairs of products is eliminated. Sawlogs can be substituted for pulpwood and pulpwood, in turn, can be substituted for fuelwood, provided that the prices of sawlogs and pulpwood, respectively, fall low enough to become competitive substitutes for pulpwood and fuelwood.

14.5 Costs

To produce up-to-date cost estimates, a literature review of land conversion, forest establishment, and timber stand management costs was conducted for the nation. Special attention was paid to the cost information pertinent to the Southeast, South Central, and Pacific Northwest Westside regions because of their relative importance in timber production (Haynes 2003). Taxes were not included in the forestry costs in order to keep them consistent with cost accounting on the agricultural side of FASOMGHG.

14.5.1 Land Conversion

Sources of land conversion costs were various Economic Research Service studies (e.g., Daugherty 1982) and expert opinion. However, most of the formal studies were dated, with most conducted before the 1980s and before significant changes in conversion technology, and so were augmented by expert opinion.

Costs are represented in each region by step functions to reflect increasing costs, as the percent of land base being converted increases. Costs for land conversion in a region are less expensive for the initial 10 percent of land converted and subsequently higher for the next 50 percent, and even more so for the final 40 percent. This reflects the increasing marginal cost of land conversion due to varying topography, moisture, and other factors.

Land conversion costs include those for land clearing, wind rowing, and burning, and any necessary leveling and removing large chunks of woody debris for seedbed preparation. Any timberland converted to agricultural land is assumed to occur after harvest of any merchantable trees, and 75% of timber volume removed in land clearing is assumed to be hauled to market

(Adams et al. 1996). Taxes were not included in the forestry costs in order to keep them consistent with cost accounting on the longer-standing agricultural side of FASOMGHG.

Constraints on the amount of timberland that could be converted to agricultural uses were derived from data from the Natural Resource Inventory by the Natural Resources Conservation Service (2001), pertaining to NIPF timberland with medium or high potential for conversion to crop land and pasture land. The data were checked against that for NRI prime farmland, representing forest, pasture land, crop land, rangeland, or other minor land uses that have good potential for cultivated crops (e.g., slope less than 5%, not excessively eroded, not wetlands, etc.). The published NRI data do not identify forestland qualifying as prime crop land below our FASOMGHG region, thus allocation of prime crop land by forest type, MIC, and age cohort is by assumption (proportional to what is in the highest forestry site group).

The equation for land conversion cost includes land conversion, windrowing, burning, and leveling and stump removal costs. Cost estimates from the first-generation FASOM modeling (Adams et al. 1996) were updated in the case of conversion costs. These cost estimates were updated from 1990 to 2002 dollars using the US Bureau of Labor Statistics (2003) Producer Price Index for all commodities.

Another important portion of the conversion cost information is estimates of acres of available prime crop land and pasture land in each state that are currently under the cover of forestland (USDA NRCS 2001). NRI data (1997 national survey) were used to estimate these land areas. To determine the proportion of forested crop land and pasture land available in each state, the ratio of “active” crop and pasture land was used to disaggregate the total prime agricultural land in forest cover. The amount of crop and pasture land eligible for conversion to timberland was established using information from Moulton and Richards (1990), as was done in the previous FASOM model. One stipulation from the first FASOM model is that reforestation establishment costs must be greater than or equal to crop to forest or pasture to forest conversion establishment costs (Adams et al. 1996).

14.5.2 Forest establishment costs

Forest establishment costs include those for site preparation, tree seedlings, and tree planting. Intermediate timber management costs include those for precommercial thinning, prescribed burning, fertilization, and any other practices between stand establishment and harvest. Establishment costs vary by FASOMGHG land class, with generally higher costs for reforested acres, such as those for FORONLY acres, and lower costs for afforesting CROPFOR and PASTFOR acres.

For regional averages of forest establishment in the South, *Forest Farmer* reports cost trends every 2-3 years in the *Manual Edition*. Cost estimates and trends over the period 1952-1994 were reported for specific forestry practices common to the South (Dubois et al. 1999, 2000, 2003). These cost data are based on surveys of forest industry, consultants, and public agencies, and most are on a per acre basis. Those practices with a high percentage of labor experienced the greatest cost increases (e.g., Dubois et al. 1999). A comparable regional synthesis of establishment and management costs does not exist for the Pacific Northwest, however.

Updated cost functions were used from the previous FASOM model to estimate establishment and growing costs on a per acre basis (Adams et al. 1996). Establishment costs for naturally regenerated stands include site preparation costs, but significantly less than for planted stands. Sources for updated cost estimates included Dubois (2003) and Cathcart (2003), primarily for establishment of planted stands in the Southern regions and Pacific Northwest Westside, respectively.

Establishment costs in the case of conversion from crop land or pasture land to forest are lower than for regeneration on timberland, because of lower site preparation costs. By land type, site preparation costs were weighted according to the difference in establishment costs between forest and crop or pasture land in Moulton and Richards (1990).

Cost adjustments pertaining to forest type conversions included adding 10% for costs of prescribed burning and herbicide treatments for conversions of forest types across softwood and hardwood bounds (Adams et al.1996). Costs were only increased 10% for one period, and then reverted back to the standard decadal cost for the type and region. Also, prescribed fire was not allowed on stands of mixed oak-pine or hardwood (Devos 1999).

14.5.3 Timber growing costs

Timber growing costs include costs of thinning, prescribed burning, fertilization, and general periodic maintenance. For the Southeast and South Central regions, information by Dubois et al. (2000) pertaining to cost and cost trends for forestry practices in the South represented the most complete source. The associated documentation is published on a regular periodic basis and encompasses a variety of timber stand treatment and cruising costs. Cost estimates from this survey were obtained for 12 Southern states and included private firms and public agencies. Additional sources were used in estimating costs for naturally regenerated pine, oak-pine, and upland and bottomland hardwoods (Amacher et al. 1997; Bates et al. 2003; Huang et al. 2003; McKee 1987; Stranturf et al. 2000; Shabman and Zepp 2000; Siry 2002; Vasievich 1983).

Literature pertaining to timber outside the South was used to estimate costs for the Pacific Northwest-Westside and the remaining regions. According to Floyd et al. (2000), "Growing costs are surveyed in the South, but no comparable survey is conducted in the West." Limited region-specific information was obtained for the Pacific Northwest-Westside using a survey of professional foresters in Oregon, while other resources were used to estimating costs for the remaining regions (Cathcart 2003; Moulton and Richards 1990; Vasievich 1983).

Growing costs for passive and low MIC aggregates are for management plans, boundary maintenance, survey and cruising, and fire protection. For medium and high MICs, intermediate treatment costs can also include precommercial thinning, fertilization, herbicide application, and prescribed burning. It is assumed that before reforestation or afforestation activities take place, landowners have a clear definition of their boundaries (e.g., historical fencing, fire breaks, etc.) and reasonable access to their land (e.g., established roads, drainage, etc.) Intermediate treatment costs were weighted for regional differences, unless the costs were directly from the region in question (Moulton and Richards 1990).

The periodic growing costs are applied every time period until the harvest takes place, while the other intermediate treatments are applied only as indicated by the specified timing in the governing MIC (e.g., precommercial thinning at age 15). Prescribed fire is not incorporated into specific MIC's or linked to the decadal costs of timber management, but implemented on a infrequent periodic basis, given the relatively small number of acres burned and the declining trend to do so on private lands (Haines et al. 2001). Prescribed fire has been excluded from the PNWW stands based on expert opinions from the Oregon Department of Forestry and Weyerhaeuser Company.

Table 14.2.1.1 Forest sector inventory strata used in the FASOMGHG Model

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Region	Land Suitability Class	Owner	Site Class	Age Cohort	Forest type	Management Intensity
Corn Belt	Forest Only	Forest Industry	High	5 year	See Table 14.2.1.1-	See Table 14.2.2.1

				3
Lake States	Crop land to Forest	Nonindustrial Private	Medium	
Northeast	Pasture land to Forest		Low	
Pacific Northwest-Eastside	Forest to Crop land			
Pacific Northwest-Westside	Forest to Pasture land			
Pacific Southwest				
Rocky Mountain				
South Central				
Southeast				

Table 14.2.1.1-2 Initial Private Timberland Inventory by Region (circa 2000)

FASOMGHG Region	Private Timberland Area (million acres)	Softwood Volume (billion cubic feet)	Hardwood Volume (billion cubic feet)
North East	69.320	27.366	76.380
Lake States	30.333	8.494	29.855
Corn Belt	27.544	1.087	27.074
South East	75.430	44.418	61.289
South Central	104.778	44.639	70.187
Rocky Mountain	21.125	20.914	5.002
Pacific North West	17.580	38.862	8.660
Pacific Southwest	7.437	18.308	5.755

Source: Smith et al. (2001); timber volumes are growing stock component (see glossary). The historical statistics (Smith et al. 2001) do not separate out the Westside and Eastside for the Pacific Northwest.

Table 14.2.1.1-3 Forest type pathways in FASOMGHG, by region.

Allowable Forest Type Pathways During Reforestation		
Region	Forest Type and MIC	Pathways
South Central and Southeast	Planted Pine MIC	Planted Pine: Conversion allowed on Natural Pine, Oak-Pine, Upland Hardwood, and Bottomland Hardwood
	Natural Regeneration - Natural Pine MIC	Natural Pine: Conversion allowed from existing Natural Pine, Planted Pine, and Oak-Pine
	Natural Regeneration - Oak-Pine MIC	Oak-Pine: Conversion allowed from existing Natural Pine, Planted Pine, and Oak-Pine
	Natural Regeneration - Upland Hardwood MIC	Upland Hardwood: Conversion allowed from existing Natural Pine, Planted Pine, Oak-Pine, and Upland Hardwood
	Natural Regeneration - Bottomland Hardwood MIC	Bottomland Hardwood: Conversion allowed from existing Natural Pine, Planted Pine, Oak-Pine, and Bottomland Hardwood
Corn Belt, Lake State, and North East	Natural Regeneration - Softwood MIC	Softwood: Conversion allowed form existing Softwood only
	Natural Regeneration - Hardwood MIC	Hardwood: Conversion allowed from existing Hardwood and Softwood
Pacific Northwest Eastside, Pacific Southwest, and Rocky Mountain	Natural Regeneration - Softwood MIC	Softwood: Conversion allowed from existing Softwood only
	Natural Regeneration - Hardwood MIC	Hardwood: Conversion allowed from existing Hardwood only
Pacific Northwest Westside	Natural Regeneration - Douglas-fir MIC	Douglas-fir: Conversion allowed from Douglas-fir and Other Softwoods
	Planted - Douglas-fir MIC	Douglas-fir: Conversion allowed from Douglas-fir, Other Softwoods, and Hardwoods
	Natural - Regeneration Other Softwood MIC	Other Softwood: Conversion allowed from Douglas-fir and Other Softwoods
	Planted -Other Softwood MIC	Other Softwood: Conversion allowed from Douglas-fir, Other Softwoods, and Hardwoods
	Natural Regeneration and Planted -Hardwood MIC	Hardwood: Conversion allowed from Douglas-fir, Other Softwood, and Hardwood
Allowable Forest Type Pathways During Afforestation		
South Central and Southeast	Planted Afforestation MIC	Planted Pine and Bottomland Hardwood
Corn Belt	Planted and Non-planted Afforestation MIC	Softwood and Hardwood
Lake State, North East Pacific Northwest Eastside, Pacific Southwest, and Rocky Mountain	Non-planted Afforestation MIC	Softwood Only

Table 14.2.1.1-4 Forest type possibilities in afforestation in FASOMGHG, by region

Region	Forest Type	Source
Corn Belt	Hardwood and Softwood	Adams 1996
Lake States	Softwood	Adams 1996
Northeast	Softwood	Adams 1996
Pacific Northwest-Eastside	Softwood	Adams 1996
Pacific Northwest-Westside	Douglas fir, other softwoods, hardwoods	Adams 1996
Pacific Southwest	Softwood	Adams 1996
Rocky Mountains	Softwood	Adams 1996
South Central	Southern pine (Pinus spp.) Bottomland Hardwood (for example, cottonwood, ash, oak, etc.)	Birdsey 1996 Murray 2003
Southeast	Southern pine (Pinus spp.) Bottomland Hardwood (for example, cottonwood, ash, oak, etc.)	

Table 14.2.1-5. Exogenous projected acres (million ac.) of developed land in 2025, by region

Region	Developed Area, 1997	Projected Developed Area, 2025	Projected population Increase, 1997 to 2025 (%)
Northeast	14.6	25-2	13
South	26.4	46.2	49
Northern Midwest	21.4	38.6	20
Southern Midwest	15.5	28.0	45
Great Plains	4.8	8.3	25
Southwest	5-3	9.9	80
Pacific Northwest	4.0	7.4	54
California	5.5	10.8	44
48 contiguous state Total	97.6	174.3	
Percent of continental US area developed	5-2%	9.2%	

Note: Projections based on population and per capita income growth projected by NPA Data Services (Alig et al. 2004).

Figure 14.2.3 Example of timber yields for different MICs: Planted Pine on Forest Industry High-Site Timberland in the South Central Region

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Table 14.2.2.1 Timber management intensity classes (MICs) in the FASOMGHG Model

Region	**Forest type**	ATLAS MIC	FASOMGHG MIC	Management Intensity
Southeast and South Central	Planted Pine	1	TRAD_PLNT_ PINE	Traditional
	Planted Pine	4	PLNT_LO_THIN	LO Thin
	Planted Pine	5	PLNT_MED	Medium
	Planted Pine	6	PLNT_MED_THIN	Medium Thin
	Planted Pine	7	PLNT_HI	High
	Planted Pine	10	PLNT_HI_THIN	High-Plus Thin
	Planted Pine	11	SHORT_ROTSWDS	Short Rotation Softwoods
	Planted Pine	12	RESERVED	Reserved
	Natural Pine	N/A	PASSIVE	Passive
	Natural Pine	FI 1 & NIPF 2	PART_CUT_LO	Partial Cut LO
	Natural Pine	FI 3 & NIPF 1	LO	LO
	Natural Pine	4	PART_CUT_HI	Partial Cut HI
	Natural Pine	6	PART_CUT_HI+	Partial Cut HI-Plus
	Natural Pine	12	RESERVED	Reserved
	Oak-Pine	N/A	PASSIVE	Passive
	Oak-Pine	FI 1 & NIPF 2	PART_CUT_LO	Partial Cut LO
	Oak-Pine	FI 3 & NIPF 1	LO	LO
	Oak-Pine	4	PART_CUT_HI	Partial Cut HI
	Oak-Pine	6	PART_CUT_HI+	Partial Cut HI-Plus
	Oak-Pine	12	RESERVED	Reserved
	Upland Hardwoods.	N/A	PASSIVE	Passive
	Upland Hardwoods.	FI 1 & NIPF 2	PART_CUT_LO	Partial Cut LO
	Upland Hardwoods.	FI 3 & NIPF 1	LO	LO
	Upland Hardwoods.	4	PART_CUT_HI	Partial Cut HI
	Upland Hardwoods.	6	PART_CUT_HI+	Partial Cut HI-Plus
	Upland Hardwoods.	12	RESERVED	Reserved
	Bottomland Hardwoods.	N/A	PASSIVE	Passive
	Bottomland Hardwoods.	FI 1 & NIPF 2	PART_CUT_LO	Partial Cut LO
	Bottomland Hardwoods.	FI 3 & NIPF 1	LO	LO
	Bottomland Hardwoods.	4	PART_CUT_HI	Partial Cut HI
	Bottomland Hardwoods	6	PART_CUT_HI+	Partial Cut HI-Plus
	Bottomland Hardwoods.	N/A	AFFOR	Afforestation

	Bottomland Hardwoods.	12	RESERVED	Reserved
Pacific Northwest-Westside	Douglas-fir	N/A	PASSIVE	Passive
	Douglas-fir	N/A	NAT_REGEN	Natural Regeneration
	Douglas-fir	N/A	NAT_REGEN_THIN	Natural Regeneration Thin
	Douglas-fir	N/A	PLANT	Plant
	Douglas-fir	N/A	PLANT_THIN	Plant Thin
	Douglas-fir	N/A	PLANT+	Plant Plus
	Douglas-fir	N/A	NAT_REGEN_PART_CUT_LO	Natural Regeneration Plus PC LO
	Douglas-fir	N/A	NAT_REGEN_PART_CUT_MED	Natural Regeneration Plus PC ME
	Douglas-fir	N/A	NAT_REGEN_PART_CUT_HI	Natural Regeneration Plus PC HI
	Douglas-fir	N/A	RESERVED	Reserved
	Other Softwood	N/A	PASSIVE	Passive
	Other Softwood	N/A	NAT_REGEN	Natural Regeneration
	Other Softwood	N/A	PLANT	Plant
	Other Softwood	N/A	PLANT_THIN	Plant Thin
	Other Softwood	N/A	NAT_REGEN_PART_CUT_LO	Natural Regeneration Plus PC LO
	Other Softwood	N/A	NAT_REGEN_PART_CUT_MED	Natural Regeneration Plus PC ME
	Other Softwood	N/A	NAT_REGEN_PART_CUT_HI	Natural Regeneration Plus PC HI
	Other Softwood	N/A	RESERVED	Reserved
Pacific Northwest-Westside	Hardwoods	N/A	PASSIVE	Passive
	Hardwoods	N/A	NAT_REGEN	Natural Regeneration
	Hardwoods	N/A	PLANT	Plant
	Hardwoods	N/A	RESERVED	Reserved
Other Regions	Hardwood	N/A	PASSIVE	Passive
	Softwood	N/A	PASSIVE	Passive
	Hardwood	1	LO	General Low
	Softwood	1	LO	General Low
	Hardwood	N/A	AFFOR	Afforestation (Corn Belt Only)
	Softwood	N/A	AFFOR	Afforestation (Corn Belt Only)
National Forest	Hardwood	N/A	PASSIVE	Passive
	Softwood	N/A	PASSIVE	Passive
	Hardwood	1	LO	Low
	Softwood	1	LO	Low
	Hardwood	2	LO_PART_CUT	Low Partial Cut
	Softwood	2	LO_PART_CUT	Low Partial Cut
	Hardwood	12	RESERVED	Reserved
	Softwood	12	RESERVED	Reserved

Forest type	FASOMGHG Type	ATLAS Numerical Equivalent
Planted Pine	PLNT_PINE	1
Natural Pine	NAT_PINE	2
Oak-Pine	OAK_PINE	3
Upland Hardwood	UP_HARD	4

Bottomland Hardwood	BOT_HARD	5
Douglas-fir	(PNWW) DOUG_FIR	1
Other Softwood	(PNWW) OTH_SWDS	2
Hardwood	(PNWW) HARDS	3
Softwood	SOFT	1
Hardwood	HARD	2

14.6 Forest processed Commodities

Logs at the mill are converted to product volumes according to sets of recovery or conversion coefficients that vary by region and product, and in some cases by time as well. Table 14-__ gives examples of these coefficients for the endogenous solidwood products in the starting period (2000) and for 2045 as derived from the TAMM model. These are the solidwood volumes (logs at the mill) in cubic feet required to produce one unit of the particular product. In the case of OSB the proportions of wood input coming from softwoods and from roundwood (as opposed to milling residues) must also be specified. OSB uses pulpwood rather than sawlogs as log input. Use of non-wood inputs (labor, energy, and other variable factors) is represented in the non-wood input relations described below. The model does not employ conversion or recovery factors for non-wood inputs.

Table 14-___. Examples of recovery coefficients for softwood lumber, softwood plywood, hardwood lumber and OSB by region and period from FASOMGHG forest sector: volume of wood required to produce one unit of the product.

	SOFTWOOD LUMBER		SOFTWOOD PLYWOOD		HARDWOOD LUMBER		OSB (Oriented Strand board)	
	WW	SC	WW	SC	LS	SC	LS	SC
	CF,LS/ BF,LT		CF,LS/SF,3/8"		CF,LS/BF,LT		CF,LS/SF,3/8"	
2000	0.105	0.133	0.060	0.053	0.172	0.184	0.056	0.056
2045	0.100	0.118	0.059	0.052	0.172	0.184	0.056	0.056
							FRACTION SOFTWOOD	
2000							0.100	0.800
2045							0.100	1.000
							FRACTION ROUNDWOOD	
2000							0.950	0.900
2045							0.950	0.900

Note: CF,LS is cubic foot, log scale; BF,LT is board foot lumber tall; SF,3/8" is square foot, 3/8" thick.

In the fiber products sector, similar recovery coefficients are employed to describe the amounts of pulpwood, recovered papers, and market pulp used per tonne of paper product produced. This is illustrated in Tables 14-___ and 14-___ for newsprint in the NE region and linerboard in the SC region. (see separate files newsprint coefficients sec 14.2.doc and linearboard coefficients sec 14.2.doc) In Table 14-___ there are four alternative newsprint production processes each with two alternative input mixes. For linerboard (Table 14-___) there are three alternative production processes with two to three alternative input mixes.

Table 14.___. Fiber input requirements (pulpwood, recovered papers, and market pulp) and costs of other inputs for newsprint in the NE region for four alternative production processes and several alternative input mixes. The newsprint product is 100% fiber [from NAPAP, Ince (1994)].

Process and Input Mix	SOFTWOOD PULPWOOD		HARDWOOD PULPWOOD	
	tonne/tonne	m3/tonne	tonne/tonne	m3/tonne
1 - Integrated to Roundwood (GW) & Chemical Pulp (75/25)				
1 - Max. Softwood (100%)	1.319	3.959	-	
2 - Min. Softwood (90% in GW; 50% in Chem. Pulp)	0.979	2.938	0.335	0.880
2 - Integrated to TMP Pulp, using some Mkt. Pulp (90/10)				
1 - Max. Softwood (100%)	1.000	3.002	-	
2 - Min. Softwood (90% in TMP; 50% in Chem. Pulp)	0.900	2.702	0.100	0.263
3 - Integrated to Deinked Recycled Pulp (100%)				
1 - ONP only	-		-	
2 - ONP & Mixed	-		-	
4 - Integrated to CTMP Pulp (100%)				
1 - Max Softwood (100%)	1.111	3.336	-	
2 - Min. Softwood (90%)	1.000	3.002	0.111	0.292

	RECOVERED PAPERS				
	ONP	OCC	Mixed	Pulp Subs.	Hi Grd Deink
	tonne/tonne				
1 - Integrated to Roundwood & Chemical Pulp (75/25)					
1 - Max. Softwood (100%)	-	-	-	-	-
2 - Min. Softwood (90% in GW; 50% in Chem. Pulp)	-	-	-	-	-
2 - Integrated to TMP Pulp, using some Mkt. Pulp (90/10)					
1 - Max. Softwood (100%)	-	-	-	-	-
2 - Min. Softwood (90% in TMP; 50% in Chem. Pulp)	-	-	-	-	-
3 - Integrated to Deinked Recycled Pulp (100%)					
1 - ONP only	1.176	-	-	-	-
2 - ONP & Mixed	0.882	-	0.385	-	-
4 - Integrated to CTMP Pulp (100%)					
1 - Max Softwood (100%)	-	-	-	-	-
2 - Min. Softwood (90%)	-	-	-	-	-

	MARKET PULP				OTHER COSTS
	Soft Kraft	Hard Kraft	Recycled	CTMP	
	tonne/tonne				$/tonne
1 - Integrated to Roundwood & Chemical Pulp (75/25)					
1 - Max. Softwood (100%)	-	-	-	-	382.80
2 - Min. Softwood (90% in GW; 50% in Chem. Pulp)	-	-	-	-	379.32
2 - Integrated to TMP Pulp, using some Mkt. Pulp (90/10)					
1 - Max. Softwood (100%)	0.111	-	-	-	336.40
2 - Min. Softwood (90% in TMP; 50% in Chem. Pulp)	0.056	0.056	-	-	336.40
3 - Integrated to Deinked Recycled Pulp (100%)					
1 - ONP only	-	-	-	-	348.00
2 - ONP & Mixed	-	-	-	-	348.00
4 - Integrated to CTMP Pulp (100%)					

1 - Max Softwood (100%)	-	-	-	-	359.60
2 - Min. Softwood (90%)	-	-	-	-	359.60

Table 14.___. Fiber input requirements (pulpwood, recovered papers, and market pulp) and costs of other inputs for linerboard in the SC region for three alternative processes and several alternative input mixes. The linerboard product is 99% fiber and 1% filler [from NAPAP, Ince (1994)].

	SOFTWOOD PULPWOOD		**HARDWOOD PULPWOOD**		
Process and Input Mix	**tonne/tonne**	**m3/tonne**	**tonne/tonne**	**m3/tonne**	
1 - Older press technology integrated to Unbl. Kraft					
1 - Max. Softwood (100%) & no recycled	1.904	4.266	-		
2 - Max. Softwood & Max. recycled (10% OCC)	1.713	3.840	-		
3 - Max. Hardwood (5%) & no recycled	1.809	4.053	0.095	0.175	
2 – New press technology integrated to Unbl. Kraft					
1 - Max. Softwood (100%) & no recycled	1.768	3.961	-		
2 - Max. Softwood & Max. recycled (25% OCC)	1.326	2.971	-		
3 - Max. Hardwood (30%) & no recycled	1.238	2.773	0.530	0.976	
3 - Based on Recycled Fiber					
1 - Using Old Corrugated	-		-		
2 - Max. use of lower grades	-		-		
	RECOVERED PAPERS				
	ONP	**OCC**	**Mixed**	**Pulp Subs.**	**Hi Grd Deink**
	tonne/tonne				
1 - Older press technology integrated to Unbl. Kraft					
1 - Max. Softwood (100%) & no recycled	-	-	-	-	-
2 - Max. Softwood & Max. recycled (10% OCC)	-	0.104	-	-	-
3 - Max. Hardwood (5%) & no recycled	-	-	-	-	-
2 - New press technology integrated to Unbl. Kraft					
1 - Max. Softwood (100%) & no recycled	-	-	-	-	-
2 - Max. Softwood & Max. recycled (25% OCC)	-	0.261	-	-	-
3 - Max. Hardwood (30%) & no recycled	-	-	-	-	-
3 - Based on Recycled Fiber					
1 - Using Old Corrugated	-	1.042	-	-	-
2 - Max. use of lower grades (20%ONP)	0.248	0.834	-	-	-
	MARKET PULP				**OTHER COSTS**
	Softwood Kraft	**Hardwood Kraft**	**Recycled**	**CTMP**	
	tonne/tonne				**$/tonne**
1 - Older press technology integrated to Unbl. Kraft					
1 - Max. Softwood (100%) & no recycled	-	-	-	-	214.60
2 - Max. Softwood & Max. recycled (10% OCC)	-	-	-	-	214.60
3 - Max. Hardwood (5%) & no recycled	-	-	-	-	212.28
2 - New press technology integrated to Unbl. Kraft					
1 - Max. Softwood (100%) & no recycled	-	-	-	-	197.200
2 - Max. Softwood & Max. recycled (25% OCC)	-	-	-	-	197.200
3 - Max. Hardwood (30%) & no recycled	-	-	-	-	193.720
3 - Based on Recycled Fiber					
1 - Using Old Corrugated	-	-	-	-	191.400
2 - Max. use of lower grades (20%ONP)	-	-	-	-	197.200

Note: OCC is old corrugated containers.

14.7 Forest Processing

Growing stock removals are computed by adjusting the total volume of wood processed for a specific product to: (i) remove the "non-growing stock" portion of the volume; and (ii) account for the loss in volume to logging residues and "other removals" not reflected in product outputs. "Other removals" comprise unutilized wood volume from cut or killed growing stock, from cultural operations such as precommercial thinnings or from timberland clearing. These several factors were derived from TAMM model input for the 2000 RPA Timber Assessment. Their original source was Forest Service estimates of roundwood products harvest by species, source (growing stock and non-growing stock) and product type (sawlog, veneer log, pulpwood, etc.) and logging residue generation by region and species (Smith et al, 2001; tables 39 and 40, pages 154-162). Table 14-__ gives a summary of factors of all types for all products. There is no variation over time. The adjustment process is described in the following equation:

$$\text{Growing Stock Removals}_{region,product} = \text{Total Removals}_{region,product}\left[\frac{(1-\text{FNGS}_{region,product})(1+\text{OREMS}_{region,product})}{(1-\text{LOGRES}_{region,product})}\right]$$

where

FNGS is the fraction of non-growing stock volume in the total wood volume that reaches a mill,
OREMS is the fraction of volume not extracted from the site in other removals,
LOGRES is the fraction of growing stock removals left as logging residue on the site, and

Table 14-__. Logging residues (LOGRES), other removals (OREMS) and non-growing stock (FNGS) fractions by region and product.

Definitions below	PNWW	PNWE	PSW	RM	LS & CB	NE	SC	SE
HLOGRES	0.0419	0.1290	0.0909	0.0593	0.1047	0.1212	0.1372	0.1378
SLOGRES	0.0457	0.0675	0.0909	0.0908	0.0414	0.0516	0.0596	0.0605
HOREMS	0.0040	0.0040	0.0013	0.0000	0.0816	0.0000	0.1351	0.1652
SOREMS	0.0004	0.0004	0.0000	0.0000	0.0353	0.0000	0.0504	0.0604
HSFNGS	0.0008	0.0008	0.0000	0.0906	0.0960	0.1162	0.0941	0.0560
SSFNGS	0.0313	0.0313	0.0816	0.0757	0.0299	0.1994	0.0258	0.0243
HVFNGS	0.2370	0.0467	0.0000	0.0000	0.0916	0.1155	0.0243	0.0094
SVFNGS	0.0860	0.0860	0.2364	0.0063	0.0972	0.1995	0.0281	0.0222
HPFNGS	0.8470	0.0530	0.7626	0.0000	0.1762	0.1816	0.1210	0.1034
SPFNGS	0.1653	0.1653	0.0000	0.2851	0.1121	0.2182	0.0797	0.1063
HRPFNGS	0.8470	0.0000	0.7626	0.0089	0.2333	0.1815	0.1305	0.1110
SRPFNGS	0.1566	0.1566	0.0000	0.2851	0.2979	0.2179	0.1345	0.1225
HOPFNGS	0.0000	0.0000	0.0000	0.0418	0.6613	0.2577	0.3401	0.2487
SOPFNGS	0.0098	0.0098	0.0330	0.3189	0.1084	0.3361	0.1213	0.1393
HFFNGS	0.3140	0.9350	0.8360	0.9400	0.8280	0.8610	0.4900	0.4470
SFFNGS	0.3590	0.7490	0.5260	0.9710	0.6500	0.9060	0.3930	0.4560

Initial letters H and S in names indicate hardwood and softwood species. For the non-growing stock fractions (FNGS), the first letters denote the product: HS, HV, HP, HRP, HOP and HF denote sawlogs (S), veneer logs (V), pulpwood (P), reconstituted panels including OSB (RP), other solid wood products (OP) and fuelwood (F), respectively, for hardwood species. Names are similar for softwoods with a preceeding S.

14.7.1 Forest non-wood input (solid wood products only)

As noted in section 7.1.8, TAMM's assumption of weak separability between wood and non-wood inputs (and its specific fixed coefficients technology assumption about wood use) makes it possible to write the inverse supply functions for the solidwood products as in equation 7.__, $P_p = F(Q, K) + (1/r_w)P_w$. The full supply representation in TAMM is as follows (note that a quadratic form is assumed for the aggregator function f in equation 7.__ which yields a linear profit function and linear product supply and factor demand functions):

$$Q_p = a_{sp} + b_{sp}[P_p + PRES_p - (L\&H_p + P_w)/r_{wp}] + c_{sp}OC_p + d_{sp}K_{p,t-1}$$

where

a_{sp}, b_{sp}, c_{sp}, and d_{sp} are coefficients estimated by econometric methods,
$PRES_p$ is residue revenue for product p,
$L\&H_p$ is log and haul cost (forest-to-mill costs measured per unit of log input) which varies by product p,
OC_p are all other costs,
P_p and P_w are the prices of product and wood input, respectively, and
$K_{p,t-1}$ is start-of-period capacity (the measure of quasi-fixed capital used in TAMM).

Residues are treated as a fixed proportion by-product, so residue revenues are added to product price. Delivered wood costs are the sum of timber (stumpage, P_w) and delivery (log and haul, $L\&H_p$) costs.

Solving for P_p,

$$P_p = -a_{sp}/b_{sp} - PRES_p + L\&H_p/r_{wp} - (c_{sp}/b_{sp})OC_p - (d_{sp}/b_{sp})K_{p,t-1} + (1/b_{sp})Q_p + P_w/r_{wp}$$

so the non-wood input term (F(Q,K) in equation 7.__) is

$$NWC_p = -a_{sp}/b_{sp} - PRES_p + L\&H_p/r_w - (c_{sp}/b_{sp})OC_p - (d_{sp}/b_{sp})K_{p,t-1} + (1/b_{sp})Q_p$$

which varies with the level of output and also over time as recovery (r_{wp}) and other components vary. Elasticities of non-wood inputs with respect to output and of total supply with respect to product price are shown in Table 14-___ for the 2000-2004 period. Non-wood inputs are highly sensitive to shifts in output for softwood lumber in interior and eastern Canada, for OSB in Canada and for hardwood lumber production in all of the eastern US regions.

Table 14-___ Elasticities of non-wood inputs with respect to output and of supply with respect to product price by region and product for the initial (2000-2004) model projection period.

<table>
<tr><th></th><th colspan="2">Softwood Lumber</th><th colspan="2">Softwood Plywood</th><th colspan="2">OSB</th><th colspan="2">Hardwood Lumber</th></tr>
<tr><th></th><th>Non-wood inputs</th><th>Own Price</th><th>Non-wood inputs</th><th>Own Price</th><th>Non-wood inputs</th><th>Own Price</th><th>Non-wood inputs</th><th>Own Price</th></tr>
<tr><td>PNWW</td><td>0.453</td><td>0.611</td><td>0.423</td><td>1.013</td><td></td><td></td><td></td><td></td></tr>
<tr><td>PNWE</td><td>0.320</td><td>0.345</td><td>0.459</td><td>0.910</td><td></td><td></td><td></td><td></td></tr>
<tr><td>PSW</td><td>0.089</td><td>1.481</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>RM</td><td>0.396</td><td>0.500</td><td>0.424</td><td>0.910</td><td>0.841</td><td rowspan="6">0.204</td><td></td><td></td></tr>
<tr><td>LS</td><td>0.213</td><td>0.820</td><td></td><td></td><td>1.281</td><td rowspan="2">8.059</td><td rowspan="2">0.206</td></tr>
<tr><td>CB</td><td></td><td></td><td></td><td></td><td>1.281</td></tr>
<tr><td>NE</td><td>1.111</td><td>0.280</td><td></td><td></td><td>0.847</td><td>7.041</td><td>0.254</td></tr>
<tr><td>SC</td><td>0.821</td><td>0.561</td><td>0.568</td><td>0.811</td><td>1.658</td><td>3.117</td><td>0.364</td></tr>
<tr><td>SE</td><td>0.496</td><td>0.766</td><td>1.194</td><td>0.529</td><td>1.665</td><td>2.309</td><td>0.472</td></tr>
<tr><td>CBCC</td><td>0.399</td><td>0.935</td><td></td><td></td><td rowspan="3">2.716</td><td rowspan="3">0.193</td><td></td><td></td></tr>
<tr><td>CINT</td><td>2.147</td><td>0.447</td><td></td><td></td><td></td><td></td></tr>
<tr><td>CEST</td><td>3.955</td><td>0.492</td><td></td><td></td><td></td><td></td></tr>
</table>

Projections of log and haul costs were derived from the 2000 RPA Timber Assessment. Projected residue revenues and capacity in these equations were also taken initially from the TAMM projections. These latter variables are determined within the FASOMGHG framework (as shadow prices of the residue balance constraints and from the endogenous capacity variables).

14.8 Wood products Demand

14.8.1 Solid Wood Products

Demands for softwood lumber, softwood plywood and OSB are the sum of demands in their several "end-uses." An end-use is a specific group of applications, for example, single family housing, manufacturing, shipping, etc. The FASOMGHG equations are derived by aggregating annual relations across end-uses for each of the products from TAMM. The original end-use demand equations are base on the technology diffusion model developed by Spelter (1984, 1985, 1992). In simplified form the model can be written as in equations 14.__ through 14.__.

NEED EQUATION NUMBERS

$$Q = \sum_{i=1}^{M} Q_i$$

$$Q_i = M_i \overline{U}_i \exp(-\frac{b}{T_t})$$

$$T_t = T_{t-1} + \frac{P_{i,p,t} - P_{i,s,t}}{P_{i,s,t}}$$

where

Q is total demand for a product (e.g., softwood lumber),

Q_i is demand in the i^{th} end-use,

M_i is a measure of the output of the ith end-use (for example, floor area of single family housing starts),

$\overline{U}_i$ is the maximum use of the solidwood product per unit of output of end-use category i,

b is a parameter to be estimated, and

$P_{i,p,t}$ and $P_{i,s,t}$ are the prices (put-in-place) of the solidwood product (p) and its substitute (s) in end-use category i in period t.

Price "put-in-place" refers to the cost of the product per unit of application, including the costs of all additional or related inputs needed to produce one unit of output of the application. For example, the cost put-in-place of OSB used in wall sheathing in a single family home includes the cost of the panel itself as well as the labor and fasteners needed to install it. The costs are measured per unit of end-use output, in this case, per square foot of floor area in a single family housing unit. If we assume fixed coefficients production in their manufacture, the put-in-place units can be viewed as "composite inputs" with a different technology for the solid wood product and the substitute (see Chambers, 1988). The notion of "diffusion" arises in this context because the response of demand to shifting relative prices of solidwood products and substitutes is gradual as the cumulative price ratio variable T changes over time. For further details of the underlying methodology see Adams and Haynes (1996). Adams et al (1992) provide a further discussion and application of this approach to derived demand for factors based on composite inputs and specific technology assumptions.

The demand for hardwood lumber was also extracted from TAMM. It was developed using an approach similar to that employed for the other solidwood products but did not include the cumulative (diffusion) price ratio term. Demand is broken out by end-use category dependent on the relative prices put-in-place of hardwood lumber and a representative substitute product. Periodic (5-year) equations were cumulated from the annual estimates in TAMM. See Adams and Haynes (1996) for further details of the hardwood sector.

Demand elasticities for the four endogenous solid wood products are shown in Table 14.__ for the average of the 1980's and 1990's and for the initial 2000-2004 period. The elasticity of softwood plywood rises sharply after the 1990's in the face of competition from OSB and rapid increases in its consumption. Consistent with the diffusion approach, the elasticity of OSB demand drops sharply as its market share grows.

Table 14-__ Demand elasticities for solid wood products derived from TAMM projection.

	Softwood	Softwood	OSB	Hardwood

	Lumber	Plywood		Lumber
1980's-1990's	-0.10	-0.10	-0.36	-0.60
2000-2004	-0.21	-0.55	-0.05	-0.51

Fiber products demand relations are of the constant elasticity form (see Zhang et al(1993,1996); Ince, 1994) and shift over time in response to changes in GDP per capita, population, and the prices of substitute goods. Table 14-__ summarizes the own price elasticities of demand for the US and Canada.

Table 14-__ Elasticities of demand by fiber product for the US and Canada from NAPAP (Zhang et al(1993,1996); Ince, 1994)

Type of Paper or Pulp	US	Canada
Newsprint	-0.22	-0.2
Uncoated. Free Sheet	-0.47	-0.2
Coated Free Sheet	-0.40	-0.2
Uncoated Roundwood	-0.54	-0.2
Coated Roundwood	-0.40	-0.2
Tissue & Sanitary	-0.26	-0.6
Specialty Packaging	-0.23	-0.6
Kraft Packaging	-0.54	-0.6
Linerboard	-0.29	-0.7
Corrugating Medium	-0.43	-0.7
Solid Bleached Board	-0.29	-0.7
Recycled Board	-0.40	-0.7
Construction Pap. & Bd.	-0.58	-0.7
Dissolving Pulp	-0.26	-0.7

14.9 International Trade in Wood products

The US has been a net importer of wood products (on a roundwood volume equivalent basis) for the past 50 years. Softwood lumber trade with Canada has received much attention in recent years, but net imports of other classes of products have also grown markedly. In the past, Canada has been the largest source of US imports of both solid wood and fiber products. This dominance has declined somewhat in the past two decades as some European and southern hemisphere countries have entered the softwood lumber and panel trade and an array of nations and regions have expanded exports in paper and paperboard products.

In the FASOMGHG forest sector, trade flows from Canada to the US are endogenous for softwood lumber, OSB, all 14 classes of fiber products and softwood pulpwood and residues. The solidwood sector also incorporates an import supply relation for softwood lumber shipments from non-Canadian sources. All other trade flows, both with Canada and the rest of the world, are exogenous and specified consistent with the Base case trade scenario assumptions in the 2000 RPA Timber Assessment.

14.9.1 Canada

14.9.1.1 Exchange rates and tariffs

Canada comprises three endogenous producing regions in the solidwood sector and two in the fiber products sector. There is one demand center in the US and one in Canada for fiber products. Canadian demand for solidwood products is exogenous and there is a single demand center in the US for solidwood products. Thus in both solid wood and fiber products Canada is treated as an excess supply region, shipping products to the US, while shipments from the US to Canada are exogenous. In the endogenous cases, trade moves in response to relative costs and prices subject to exchange rate assumptions and any tariffs. Exchange rate history and projections (from the 2000 RPA Timber Assessment) are shown in Figure 14.___. Note that this is the real exchange rate defined as:

Real exchange rate=Nominal exchange rate*relative prices in trading countries.

In the present case the real exchange rate is computed as

($US/$C)(CPPI/USPPI),

where CPPI and USPPI are the Canadian and US all commodity producer price indexes, respectively.

Figure 14.2. Real US/Canadian exchange rate 1950-2003 with projections to 2050 from *2000 RPA Timber Assessment.*

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US tariffs (or effective tariffs) on softwood lumber imported from Canada have varied markedly over the past decade. In the base FASOMGHG projection we assume continuation of the current (2003-2004) tariff structure amounting to approximately at 27.2% rate *ad valorem* (see Adams, 2003, for a discussion of the effects of changing tariffs on trade and timber resources in the context of the TAMM model). US tariffs on fiber products are limited and have been quite stable over the past several decades. They are ignored in the base case analysis.

14.9.1.2 Canadian timber supply

While there is a small area of private timberland in Canada, the bulk of the timberland base is held and managed by the provinces. The volume of timber offered for sale (or annual allowable cut, AAC) from these lands, like their public counterparts in the US discussed below, is determined by processes independent of timber prices (and often management costs). In addition, the current timber inventory and timber growth and yield data for Canada do not allow the construction of a compact timber inventory projection model (such as ATLAS) as was possible for the US. As a consequence the "supplies" of sawtimber and pulpwood in Canada are represented by: (i) a set of delivered wood cost relationships developed in the TAMM and NAPAP models and (ii) specific assumptions about future trends in the AACs in response to various political pressures in Canada.

Delivered wood cost relations for sawtimber derive from historical analysis of costs and wood volumes. The constant elasticity relations have own-price elasticities of delivered wood volumes of 1.22 for the BC Coast region, 0.67 for the Canadian interior region, and 1.33 for eastern Canada. The relations do no shift over time. Canadian roundwood pulpwood supply is represented by a combined minimum price (harvest and haul cost) and quantity upper bound. Volume is available at the fixed price up to the bound. Roundwood pulpwood has accounted for only about 40% of the total pulpwood receipts at mills (roundwood + residues) in the past. Projections, based on assumptions in the 2000 RPA Timber Assessment, envision that it will continue to provide a similar proportion in the future remaining in the neighborhood of recent harvest levels (about 35 million m3). Residues from lumber mills provide the remaining 60% of pulpwood receipts and are determined within the model.

Public forest lands in Canada face an array of pressures to broaden the objectives for their management, to limit harvests to sustainable levels and to provide land for native peoples. As a result, AACs have been falling in some provinces, and in the British Columbia Coast and Interior Canadian regions actual or realized harvest has fallen as well. This is, at present, an highly controversial issue in Canada, and the extent and timing of any future reductions in allowable cut and harvest are uncertain. The base projection, following assumptions in the 2000 RPA Timber Assessment, assumes that harvest restrictions will continue in western provinces and be enacted in eastern provinces within the next decade, gradually reducing softwood sawtimber harvest and exports of softwood lumber to the US. Only softwood sawtimber harvests are affected by these limitations.

In the BC Coast region it is assumed that allowable softwood sawtimber harvest will continue its decline of the past decade and will rise no higher than 400 million ft^3. In the Canadian Interior region it was assumed that softwood sawtimber harvest by 2010 will rise no higher than the peak level observed in 1992 (some 2.0 billion ft^3 per year). Between 2010 to 2020 this limit is reduced to the lowest harvest level observed in the decade of the 1990's (roughly 1.75 billion ft^3 per year) and remains there for the rest of the projection. In the Eastern Canadian region, where AAC's are at present substantially higher than harvest, it was assumed that harvest would increase no more than 15 percent above approximate 1999 levels (to about 2.6 billion ft^3 per year) in the period to 2010. Between 2010 and 2020 the limit falls back to roughly the average level observed during the 1990s (about 2.0 billion cubic feet per year)

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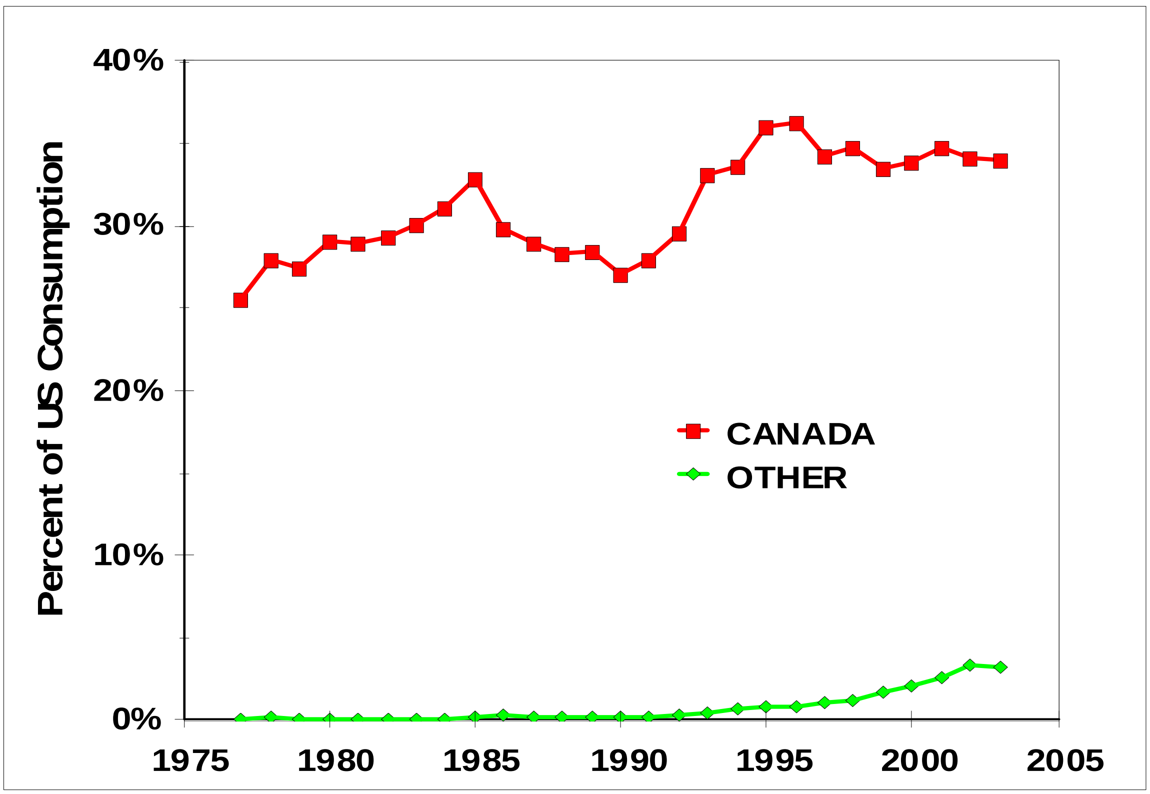

Figure 14-1. Share of Canadian and non-Canadian imports in US softwood lumber consumption.

14.9.1.3 Other world regions

Trade with non-Canadian countries and regions is treated as exogenous except for import flows of softwood lumber. Over the period from 1993 to 2003, non-Canadian softwood lumber imports grew from 0.5% of US consumption to 3.2%, a volume gain of more than 1.5 billion board feet. As shown in Figure 14.__, non-Canadian imports have accounted for the continued growth in the share of imports in US consumption while the Canadian share has stabilized. In light of this past growth, and prospects for continued expansion in the future, we included the TAMM estimate of non-Canadian import supply in the FASOMGHG solid wood sector. This is a constant elasticity function with an own price elasticity of 1.5 established on a judgmental basis. The import supply curve shifts (exogenously) over time based on Forest Service estimates of future supply potential from these sources. In the 2000 RPA Timber Assessment, this approach led to projected non-Canadian softwood lumber imports of 7.3 billion board feet by 2020 and 10.5 billion feet by 2050.

14.10 Public land harvests

Timber harvest from public lands in the US is established by an array of policy-making processes varying from the state-local to the federal level. In general, however, harvest determination--the so-called "allowable sale quantity" or volume offered for sale--is independent of market price for timber and may be unrelated as well to levels of timber inventory and growth. As a consequence we treat public timber harvests as exogenous in FASOMGHG, with future projections for the base case derived from 2000 RPA Timber Assessment base assumptions. Historical and projected volumes of sawtimber are shown in Figure 14-__ for the US totals. The modest increase in national forest harvest reflects assumptions of expanded restoration thinning programs in western states but only toward the levels allowed under current management direction. The impacts of any implementation of the Healthy Forests Restoration Act of 2003 are not reflected in these volumes

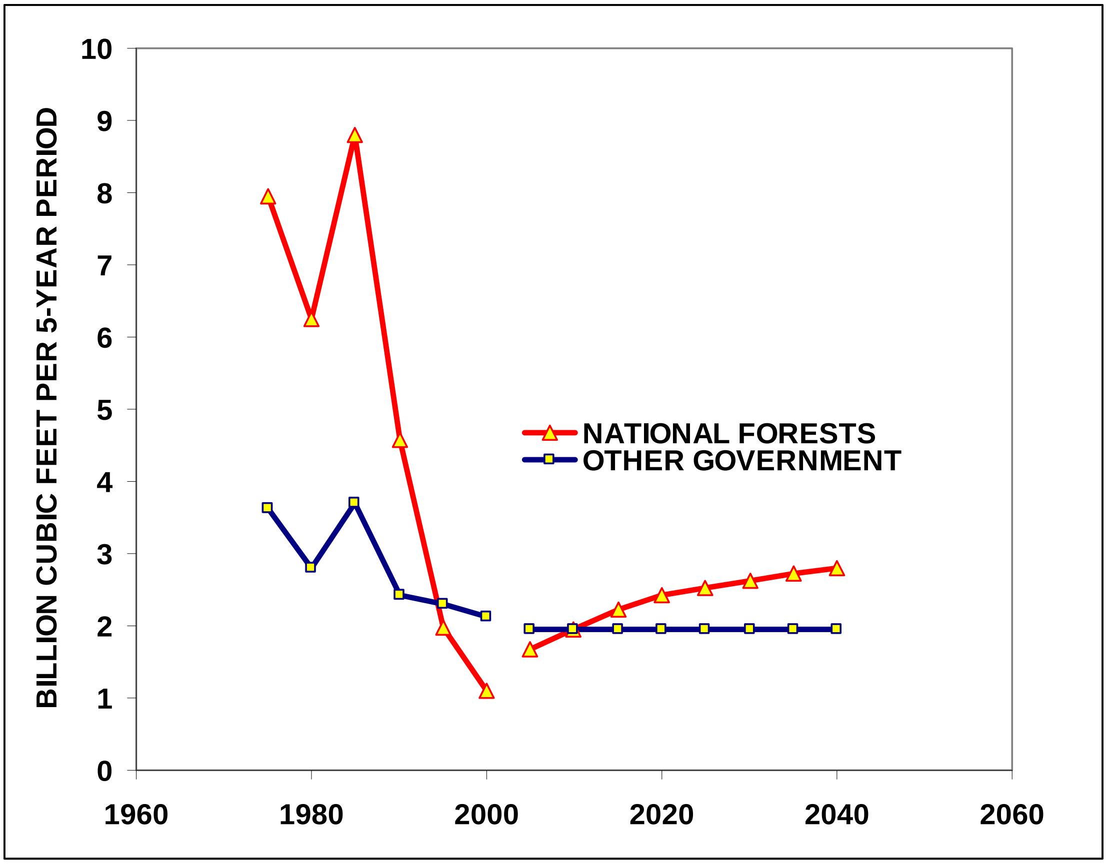

Figure 14-3. Sawtimber harvests on national forests and other government lands in the US: estimated actual levels 1975-2000, projections from 2000 RPA Timber Assessment.

s.

15 CHAPTER 14 AGRICULTURE SECTOR ECONOMIC DETAIL (MCCARL)

15.1.1 Commodities disappearance

15.1.2 Production budgets

15.1.2.1 Crops

15.1.2.2 Livestock

15.1.3 Factor supply

15.1.3.1 land

15.1.4 types

The availability on these two types of land was derived from USDA NAS county reporting and Agricultural Statistics. The regional prices for land were derived from the information in Farm Real Estate Market Developments. Cash rental prices of land were used to reflect annual opportunity costs to the owners. The third land type is AUM grazing land. The AUM supply is divided into public and private grazing on the subregional level. Public grazing is available at a constant price while private grazing can be obtained by an upward-sloping supply schedule. Information on public grazing comes from the Grazing Statistical Summary by USDA Forest Service and Public Land Statistics by the Bureau of Land Management in the US Department of the Interior. Private grazing information comes from the estimates in An Analysis of the Range Forage Situation in the US: 1989-2040 by L.A. Joyce. Information on grazing fees originates from Estimating Forage Values for Grazing National Forest Lands by W.F. Hahn et al. and the Bureau of Land Management.

Three major types of land are specified. The first one (type 1) is land suitable for crop production. Depending on ASM version, crop land may be treated as a single type or in four erodibility classes. The second land type (type 2) is suitable for pasture or grazing. The availability on these two types of land by states or regions was derived from Agricultural Statistics. The regional prices of these land were derived from the information in Farm Real Estate Market Developments. Cash rental prices of land were used to reflect annual opportunity costs to the owners. The third land type is AUM grazing land. The AUM supply is divided into public and private grazing on the subregional level. Public grazing is available at a constant price while private grazing can be obtained by a upward- sloping supply schedule. Information on public grazing comes from the Grazing Statistical Summary by USDA Forest Service and Public Land Statistics by the Bureau of Land Management in the US Department of the Interior. Private grazing information comes from the estimates in An Analysis of the Range Forage Situation in the United States: 1989-2040 by L.A. Joyce. Information on grazing fees originates from Estimating Forage Values for Grazing National Forest Lands by W.F. Hahn, et al. and the Bureau of Land Management.

Conservation Reserve Program (CRP) acres, signups 1 through 9, were subtracted from the crop land base by subarea and crop land class. Available CRP data did not allow a direct allocation of enrolled acres by FASOMGHG crop land class. However, USDA analysis (Osborn et al., 1992) of the available data provided guidelines for allocation of the CRP by ASM crop land classes indicating that about 25 percent of the CRP enrollment went into non-highly erodible land (ei < 8.0). In turn, land was allocated so the CRP proportion in svei and mdei could not exceed 75 percent; likewise, restrict for each subarea that only 75 percent of svei and mdei could be in the CRP. First, CRP was allocated into svei and mdei, proportional to their occurrence in total land, until either 75 percent of the CRP was allocated or 75 percent of svei and mdei devoted to CRP. Then, the remainder of the CRP was allocated to loei and w3-8 proportionate to their occurrence in the region.

The labor input also include two components: family labor and hired labor. The model requires specification of a maximal amount of family labor available, and a reservation wage for family labor. The additional labor to be hired is based on an inducement wage rate which is higher than the reservation wage. The regional information about the quantities and wages was obtained from Farm Labor.

The water input is also divided into fixed (or surface) and variable available (or pumped ground) water and is supplied at the subregion level. The fixed water is available for a constant price but the amount of variable water is provided according to a supply schedule where increasing amounts of water are available for higher prices. The information on water came from USDA and NASS sources who used the Farm and Ranch Irrigation Survey and other government sources in its formation.

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15.1.4.1 AUMs

15.1.4.2 labor

15.1.4.3 water

15.1.4.4 Other inputs

15.1.5 Crop mixes

15.1.6 Livestock mixes

15.1.7 Agricultural Product Demand

Both supply and demand information (i.e., prices, quantities, slopes and/or elasticities) are required in the model. The total supply consists of domestic production from all agricultural regions and imports. Total demand is made up of domestic and foreign (or export) components. Domestic demand includes food consumption, CCC stock, livestock feed and processing. Transportation costs to the market are included in the supply budget. Livestock feed and processing demands are endogenously determined. The prices and quantity data came from Agricultural Statistics, Agricultural Prices Annual Summary, and Livestock and Meat Statistics Supplement. Elasticity, slope, and other information came from Baumes, Burton, Tanyeri-Abur and Bob House in the USDA.

15.1.8 International Trade in Agricultural Products

15.1.9 Biofuels: additional detail

Two opportunities — Ethanol and biofuel for power plants

Biomass production for power plant use required several new production possibilities be added:

Diversion of mill residues from traditional pulp and paper or other uses;

Collection of logging residue or harvest of whole trees for chipping, and shipment to a power plant;

Production and hauling of switch grass and short rotation woody crops for biomass

Treatment of power plant use of biomass to the point where the energy in biomass is on an equivalent basis with the energy from coal; (100 mega watt plant) Ira Shavel, Mark Shenckel and Bob Shackleton made up numbers for this)

Treatment of the possible use of wood chips from short rotation woody crops for pulp and paper production.

15.1.10 Non-CO_2 Environmental Indicators (McCarl)

15.1.10.1 Natural resource use (land, water,…)

15.1.10.2 Nutrient loadings (N,P,K, erosion,…)

15.1.10.3 Pesticide loadings

c) Cross-Sector Land Interaction (McCarl)

d) GHG Accounting

i) Forest Sector GHG Accounting (Murray & Depro)

ii) Agriculture Sector GHG Accounting (McCarl)

e) Non-CO2 Environmental Indicators (McCarl)

i) Natural resource use (land, water,…)

ii) Nutrient loadings (N,P,K, erosion,…)

4) Model Baseline (McCarl, Adams, Alig)

Describe the process by which the model baseline is constructed and simulated (and compared to other projections?)

a) Economic variable projections (note: FASOMGHG doesn't normally present absolute levels for these, but indices relative to the baseline. For baseline purposes, could index based of bas year value, 2000?)

i) Forest sector

(1) Prices

(2) Quantities: production,consumption, trade

ii) Agriculture Sector

(1) Prices

(2) Quantities: production,consumption, trade

b) Land use projections

i) Timberland

ii) Crop land

iii) Pasture land

iv) Other

c) GHG projections

i) Forest sector

(1) Carbon sequestered in forests

(2) Carbon sequestered in products

ii) Agriculture sector

(1) Carbon sequestered in soils

(2) Non-CO2 emissions

(3) CO2 emissions from fossil fuel use

(a) On-farm

(b) Upstream / input use?

(4) Biofuel offsets

SECTION 5: FASOMGHG OUTPUT AND VALIDATION

16 CHAPTER 15 BROAD CATEGORIZATIONS OF OUTPUT

The FASOMGHG solution is addressed here both in terms of the information it yields and its economic properties. The FASOMGHG objective function involves the maximization of the present value of consumers' plus producers' surpluses net of transport and capacity costs. It depicts (assumes), therefore, a multi-period simulation of economic activity in competitive sectors under perfect foresight of future price conditions. The sizes of timberland holdings are assumed to be small enough that owners do not individually affect prices but are knowledgeable of future wood product prices and land opportunity costs. Harvest decisions are made so that stands are harvested at the point where the (marginal present) value of wood and carbon growth (if priced) is no larger than the (present value of) marginal costs of maintaining the stand plus the marginal opportunity cost of holding the land in the current stand for an additional period (the present value of future rotations). In addition, land will shift into forestry from agriculture if the expected returns in forestry exceed the returns in agriculture over the remaining time periods in the model plus the terminal values. The decision regarding transferring land to agriculture would involve the opposite considerations.

The solution to the nonlinear programming problem provides information in eight areas:

- Consumers' and producers' welfare
- Agricultural production and prices
- Forest area and inventory volumes
- Harvest levels and prices
- Wood product output and prices
- Land and forest asset values
- Carbon sequestration amounts and "prices"
- Land transfers

Appendix D gives a definition of output items from a current version of FASOMGHG.

- Consumer and producer welfare -- As previously stated, the FASOMGHG objective function represents the net present value of consumers' and producers' surpluses in the two sectors. Consumers' surplus is calculated in both sectors. Producers' surplus is calculated regionally. Thus, the model produces information about the distribution of the present and future values of consumers' and producers' surpluses over both space and time.
- Agricultural production and prices -- FASOMGHG provides regional level information about the market-clearing production and price levels for all of the ASM commodities by time period. Regional production levels for crops can be further broken down into average yield levels and acreage harvested. Price levels for agricultural products are endogenous in FASOMGHG.
- Agricultural factor use and prices -- Tree planting programs have the potential to reduce input use by farmers. Annual management costs associated with tree plantations are considerably below agricultural production costs. Sufficiently large reductions in input use by farmers may cause the prices of some inputs, such as hired labor and water, to decrease. FASOMGHG contains input supply curves for land and hired labor. Consequently, price (and cost) impacts on these inputs are an output of FASOMGHG. The impacts of reductions in the use of other inputs can be measured, in aggregate, in terms of cost decreases to farmers, or as revenue decreases to input suppliers (on the other side of the balance sheet).
- Forest inventory levels -- For each ten year period in the simulation, FASOMGHG reports regional inventory levels by owner, land use suitability, forest type/species, site class, management regime, and age -- in other words, by each of the dimensions that characterizes a representative inventory aggregate in the model.
- Harvest levels and prices -- Harvest levels are provided by FASOMGHG at the same level of detail as other inventory statistics. Prices may be examined at either the national or regional levels.
- Wood product output and prices -- Levels of wood product output levels, by period, are provided for each of the three products (sawlogs, pulp, and fuelwood), at least by region and forest-type. Price levels for these products are endogenous.
- Land and forest asset values -- Because FASOMGHG simulates the competition between forest and agricultural activities for land, FASOMGHG produces information about marginal land and forest asset values over time. Marginal land values for agricultural and forestland can be determined from shadow prices for the equations representing the potential reforested land balance and agricultural land balance. Asset values for regional inventories can be calculated from this information using information about volumes per acre from the solution to the NLP.
- Carbon sequestration amounts and prices -- FASOMGHG produces region- and national-level information about the total amount of carbon in storage in each period and the

storage rate (i.e., change in storage) during each period. If carbon is "forced" into the model, then FASOMGHG will generate an estimate of the shadow price associated with that requirement, provided that the constraint is binding.

- Land transfers -- An important feature of FASOMGHG is the intersectoral linkage between agriculture and forestry. FASOMGHG was designed so that transfers of land between sectors would occur endogenously within the model as a result of intertemporal economic forces. Thus, an important output of FASOMGHG is the listing of land transfers in each time period. These transfers are shown by region, land class, and sector (from - to) for each time period.

FASOMGHG's key endogenous variables include

- commodity and factor prices;
- production and export and import quantities;
- land use;
- management strategy adoption;
- resource use;
- economic welfare measures:
    - producer and consumer surplus,
    - transfer payments,
    - net welfare effects,
- environmental impact indicators;
    - GHG emission/absorption (CO_2, CH_4, N_2O), and
    - surface, subsurface, and groundwater pollution for nitrogen, phosphorous, and soil erosion.

17 CHAPTER 16 GAMS IMPLEMENTATION

This appendix details the structure and sequence of the files that make up the FASOMGHG model. FASOMGHG is implemented in the GAMS algebraic modeling language (Brooke et al. 1988, McCarl, 2005). The model is made up of a number of files. This is done to allow separation of distinctly different types of data and to allow disciplinary experts to work on selected parts of the model. Functionally the program can be divided several ways. The division we describe separate files into categories according to whether they involve data, data calculations, model specification, analysis execution and report writing and/or model support. Distinctions will also be made between unifying files, forestry files, agricultural files and carbon files.

17.1 File Structure

Table 17-1 gives an alphabetic list of each of the FASOMGHG files. These files may also be classified in terms of their function and aim. A listing of the files, along those lines, is given below in Table 17-2.

Table 17-1. Alphabetic list and brief description of the FASOMGHG files

Filename	Description
allofit.gms -- integrates the data files for FASOMGHG	
calc_agcondition.gms-- calculates where production is located	
calc_aggregate.gms -- aggregates subregion ag data to regions	
calc_agliveghg.gms-- calculates livestock GHG emission factors	
calc_agsetup.gms -- calculates data for ag model setup mainly the profit calculations	
calc_fixregs.gms-- calculates regional incidence of types of production	
carbon_compute.gms -- computes forestry stand carbon data	
cplex.opt -- option file for CPLEX solver	
data_agall.gms—unifies all agricultural data	
data_agbiomass.gms-- data on moving wood products into biofuels	
data_agcemission_rawdata.gms-- data on agricultural emissions	
data_agcostname.gms -- defines agricultural cost item names	
data_agcropbudsoil.gms-- data giving agricultural crop budgets	
data_agcropmix.gms -- data on agricultural crop mix	
data_agdevelopment.gms-- contains data on ag land moving to developed use	
data_agdynamic.gms-- data on agricultural yield and other dynamic growth	
data_agelectricemit.gms-- data on emissions when generating electricity with coal	
data_agfeedprocess.gms -- defines names of feed blend alternatives	
data_agfeeds.gms -- defines agricultural blended feed commodity names	

data_agghglivestock.gms-- data on GHGs from manure and enteric fermentation
data_agghgmitigate.gms-- data on biofuels combustion and fossil fuel emissions
data_agghgnonco2.gms-- data on agricultural nonco2 emissions and management
data_agghgreglivestock.gms-- data on manure and enteric ferment management
data_agghgsoil.gms-- data on initial tillage practices by soils
data_aginputname.gms -- defines agricultural input item names
data_aginputprice.gms -- data for prices of agricultural inputs
data_aglivebuds.gms-- data giving agricultural livestock budgets
data_agmisc.gms-- data on population by region used in welfare allocation
data_agnatmix.gms-- data on agricultural crop mix
data_agprimary.gms -- defines agricultural primary commodity names
data_agprocess.gms-- data on national agricultural processing
data_agprocessregional.gms-- data on regional agricultural processing
data_agprocessset.gms -- defines the name of the agricultural processing alternatives
data_agresource.gms-- data on initial land and labor, water and AUMS supply
data_agsecondary.gms -- defines agricultural secondary commodity names
data_agsoilcarb.gms-- data on CENTURY and EPIC soil carbon sequestration
data_agsubreg.gms -- names of the agricultural subregions
data_agsubregtoreg.gms -- defines how subregions fall into regions
data_agsupdem.gms -- data for agricultural commodity demand, export and import
data_agtransport.gms-- data on transportation
data_basicsets.gms -- defines the basic regional and time sets
data_carbon_biomassmodel.csv -- tree biomass data for carbon accounts
data_carbon_trees.gms -- brings in all tree carbon data
data_carbon_weightbyrpaland.csv -- carbon weighting data
data_carbon_undercwd.csv—understory data for carbon accounting
data_fasomreg.gms -- names of the FASOMGHG overall regions
data_forall.gms -- integrates all the forest data
data_forcanval.gms -- contains US Canada trade and stumpage supply adjusters
data_forcapacity.gms -- contains wood product manufacturing capacities
data_forconvert.gms -- contains cost per acre to convert to agriculture use
data_fordevelopment.gms -- contains data on forest land moving to developed use
data_forexist.gms -- contains the timber growth and yield curves for existing forests
data_forexistcost.gms -- contains cost for existing stands
data_forexistpc.gms-- contains the partial cut and thin yields for existing forests
data_forfuelusage.gms -- -- contains forest fossil fuel use for production
data_forinvent.gms -- contains the initial forest inventory data
data_forlogsupdem.gms -- contains public and Canada log supply/demand
data_formcoefs.gms -- contains wood product manufacturing data
data_forminiharv.gms -- contains minimum harvest ages for stands
data_fornew.gms -- contains timber growth and yield for afforested and reforested stands
data_fornewcost.gms -- contains cost for afforested and reforested stands
data_fornewpc.gms -- contains the partial cut and thin yields for new forests
data_forproducts.gms -- defines the wood product commodity names
data_forrecycle.gms -- contains wood product related recycling data
data_forrotationage.gms-- contains typical rotation ages for stands
data_forsticky.gms -- contains investment cost limits for establishing new stands

data_forsupdem.gms -- contains wood product supply and demand curves
data_ghg.gms -- defines a number of items about GHG coverage
data_ghgtype.gms -- defines the names of the GHG accounts in the model
data_landtransfer.gms -- collects all forest to and from ag land transfer data
model_bounds.gms-- defines upper and lower bounds for model
model_scale.gms -- defines scaling factors for model
model_seperable.gms -- contains data to set up grid point approximations
model_setup.gms -- sets up miscellaneous model related parameters
model_structure.gms -- defines model structure and initially solves
model_update.gms—updates incidence of forest stands and ag crops
policy_model.gms -- contains data about policy setup of model
report_agcal.gms -- computes single run agricultural report
report_carboncal.gms -- computes single run GHG report
report_comparecal.gms -- computes comparative run report
report_comparesetup.gms-- sets up parameters for a cross scenario report
report_finalcal.gms -- displays cross scenario report
report_forcal.gms -- computes single run forestry report
report_forresultsput.gms -- saves forestry report in put files
report_ghgtype.gms -- computes single run GHG report
report_onerun.gms -- does report writing on solutions
report_runsummarytables.gms -- computes cross run summary report
report_setup.gms -- sets up parameters for a single run report

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Table 17-2. File grouping by major model component

Sector or FunctionData	Data Calculation	Model Specification	Report Writing		
Forest Sector	data_forall.gms		Model_update.gms	model_bounds.gms	report_forcal.gms
	data_forcapacity.gms		carbon_compute.gms	model_seperable.gms	report_forresultsput.gms
	data_forcanval.gms		calc_fixregs.gms model_scale.gms		
	data_forconvert.gms		model_setup.gms		
	data_fordevelopment.gms		model_structure.gms		
data_forexist.gms					
data_forexistcost.gms					
data_forexistpc.gms					
data_forfuelusage.gms					
data_forinvent.gms					
data_forlogsupdem.gms					
data_formcoefs.gms					
data_forminiharv.gms					
data_fornew.gms					
data_fornewpc.gms					
data_fornewcost.gms					
data_forproducts.gms					
data_forrecycle.gms					
data_forrotationage.gms					
data_forsticky.gms					
data_forsupdem.gms					
policy_model.gms					
Agricultural Sector	data_agall.gms		calc_agcondition.gms	model_bounds.gms	report_agcal.gms
data_agcostname.gms	calc_aggregate.gms		model_seperable.gms		
data_agbiomass.gms	calc_agliveghg.gms		model_scale.gms		
data_agcemission_rawdata.gms	calc_agsetup.gms	model_setup.gms			
data_agcropbudsoil.gms	calc_fixregs.gms	model_structure.gms			
data_agcropmix.gms					

data_agdevelopment.gms
data_agdynamic.gms
data_agelectricemit.gms
data_agfeedprocess.gms
data_agfeeds.gms
data_agghglivestock.gms
data_agghgmitigate.gms
data_agghgnonco2.gms
data_agghgreglivestock.gms
data_agghgsoil.gms
data_aginputname.gms
data_aginputprice.gms
data_aglivebuds.gms
data_agmisc.gms
data_agnatmix.gms
data_agprimary.gms
data_agprocess.gms
data_agprocessregional.gms
data_agprocessset.gms
data_agresource.gms
data_agsecondary.gms
data_agsoilcarb.gms
data_agsubreg.gms
data_agsubregtoreg.gms
data_agsupdem.gms
data_agtransport.gms
policy_model.gms

GHG model data_agbiomass.gms calc_agliveghg.gms report_carboncal.gms
data_agghglivestock.gms carbon_compute.gms report_ghgtype.gms
data_agghgmitigate.gms
data_agghgnonco2.gms
data_agghgreglivestock.gms
data_agghgsoil.gms
data_carbon_biomassmodel.csv
data_carbon_trees.gms
data_carbon_weightbyrpaland.csv
data_carbon_undercwd.csv
data_agelectricemit.gms
data_ghgtype.gms
data_ghg.gms
data_ghgtype.gms

Unifying	allofit.gms	model_update.gms	model_bounds.gms	report_onerun.gms
	data_basicsets.gms	calc_fixregs.gms	model_seperable.gms	report_comparecal.gms
	data_fasomreg.gms		model_scale.gms	report_comparesetup.g
	data_landtransfer.gms		model_setup.gms	report_finalcal.gms
	policy_model.gms		model_structure.gms	report_runsummarytables
			cplex.opt	report_setup.gms

17.2 Run File Sequence and Control Switches

The basic method is to run three files, largely in sequence using the file aaab.gms for the large model or aaa.gms for a small version. The files run are in the order given below, with a brief description of their function.

Allofit.gms	Includes all agricultural, forestry, and carbon data as well as associated data calculations
Model_structure.gms	Defines the FASOMGHG optimization model
Report_onerun.gms	Report writer

Users may also use an advanced basis in the case of problem cold starts. Using the GDX savepoint option and the later loadpoint writes and incorporates that basis.

FASOMGHG contains two switches that may be set which alter the type of model being analyzed. These are set at the top of the FAMODEL but may be reset anywhere below that point. These switches and their functions are:

YESAG	A switch which controls whether the ag model is generated. A nonzero value activates the ag model while a zero value suppresses it.
YESFOR	A switch which controls whether the forestry model is generated. A nonzero value activates the forestry model while a zero value suppresses it. When both YESFOR and YESAG are nonzero the full linked FASOMGHG two sector model is solved.

17.3 File Functions and Sequence

As previously stated, there are five files executed by the batch file. These files call various associated files and control the model setup, solution, and output processes. These files are discussed further below.

Detailed Specifications for Each Main File

ALLOFIT.GMS

This file includes all the FASOMGHG data. The
include files:

data_basicsets.gms -- defines the basic regional and time sets

data_fasomreg.gms -- names of the FASOMGHG overall regions

data_agsubreg.gms -- names of the agricultural subregions

data_agsubregtoreg.gms -- defines how subregions fall into regions

data_agprimary.gms -- defines agricultural primary commodity names

data_agsecondary.gms -- defines agricultural secondary commodity names

data_agfeeds.gms -- defines agricultural blended feed commodity names

data_forproducts.gms -- defines the wood product commodity names

data_aginputname.gms -- defines agricultural input item names

data_agcostname.gms -- defines agricultural cost item names

data_ghgtype.gms -- defines the names of the GHG accounts

data_agprocessset.gms -- defines the name of the agricultural processing alternatives

data_agfeedprocess.gms -- defines names of feed blend alternatives

data_ghg.gms -- defines a number of items about GHG coverage

data_ghgtype.gms gms -- defines the names of the GHG accounts in the model

data_forall.gms -- integrates all the forest data

data_forproducts.gms -- defines the wood product commodity names

data_forinvent.gms -- contains the initial forest inventory data

data_forexist.gms -- contains the timber growth and yield curves for existing forests

data_forexistpc.gms-- contains the partial cut and thin yields for existing forests data_fornew.gms -- contains timber growth and yield for afforested and reforested stands

data_fornewpc.gms -- contains the partial cut and thin yields for new forests

data_fornewcost.gms -- contains cost for afforested and reforested stands

data_forexistcost.gms -- contains cost for existing stands

data_forminiharv.gms -- contains minimum harvest ages for stands

data_forrotationage.gms-- contains typical rotation ages for stands

data_forfuelusage.gms -- -- contains forest fossil fuel use for production

data_forsticky.gms -- contains investment cost limits for establishing new stands

data_forsupdem.gms -- contains wood product supply and demand curves

data_forlogsupdem.gms -- contains public and Canada log supply/demand

data_forcapacity.gms -- contains wood product manufacturing capacities

data_formcoefs.gms -- contains wood product manufacturing data

data_forcanval.gms -- contains US Canada trade and stumpage supply adjusters

data_forrecycle.gms -- contains wood product related recycling data

data_agall.gms -- unifies all agricultural data

data_agprimary.gms -- defines agricultural primary commodity names

data_agsecondary.gms -- defines agricultural secondary commodity names

data_agfeeds.gms -- defines agricultural blended feed commodity names

data_agfeeds.gms -- defines agricultural blended feed commodity names

data_agcostname.gms -- defines agricultural cost item names

data_aginputname.gms -- defines agricultural input item names

data_agprocessset.gms -- defines names of the agricultural processing alternatives

data_agfeedprocess.gms -- defines names of feed blend alternatives data_agfeedprocess.gms -- defines names of feed blend alternatives

data_agsupdem.gms -- data for agricultural commodity demand, export and import

data_aginputprice.gms -- data for prices of agricultural inputs

data_agcropmix.gms -- data on agricultural crop mix

data_agnatmix.gms-- data on agricultural crop mix

data_agresource.gms-- data on initial land and labor, water and AUMS supply

data_agcropbudsoil.gms-- data giving agricultural crop budgets

calc_fixregs.gms-- calculates regional incidence of types of production

data_aglivebuds.gms-- data giving agricultural livestock budgets

data_agprocess.gms-- data on national agricultural processing

data_agprocessregional.gms-- data on regional agricultural processing

data_agtransport.gms-- data on transportation

data_agbiomass.gms-- data on moving wood products into biofuels

data_agmisc.gms-- data on population by region used in welfare allocation

data_agghgmitigate.gms-- data on biofuels combustion and fossil fuel emissions

data_agelectricemit.gms-- data on emissions when generating electricity with coal

data_agghglivestock.gms-- data on GHGs from manure and enteric fermentation

data_agghgreglivestock.gms-- data on manure and enteric ferment management

data_agghgsoil.gms-- data on initial tillage practices by soils

data_agcemission_rawdata.gms-- data on agricultural emissions

data_agsoilcarb.gms-- data on CENTURY and EPIC soil carbon sequestration data_agghgnonco2.gms-- data on agricultural nonco2 emissions and management

calc_agcondition.gms-- calculates where production is located

calc_agliveghg.gms-- calculates livestock GHG emission factors

data_agdynamic.gms-- data on agricultural yield and other dynamic growth

calc_fixregs.gms-- calculates regional incidence of types of production

data_landtransfer.gms -- collects all forest to and from ag land transfer data

data_forconvert.gms -- contains cost per acre to convert to agriculture use

data_fordevelopment.gms -- contains data on forest land moving to developed use

data_agdevelopment.gms-- contains data on ag land moving to developed use

policy_model.gms -- contains data about policy setup of model

model_seperable.gms -- contains data to set up grid point approximations

calc_agsetup.gms -- calculates data for ag model setup mainly the profit calculations

model_setup.gms -- sets up miscellaneous model related parameters

model_update.gms—updates incidence of forest stands and ag crops

model_update.gms—updates incidence of forest stands and ag crops

calc_aggregate.gms -- aggregates subregion ag data to regions

data_carbon_trees.gms -- brings in all tree carbon data

data_carbon_weightbyrpaland.csv -- carbon weighting data

data_carbon_biomassmodel.csv -- tree biomass data for carbon accounts

data_carbon_undercwd.csv—understory data for carbon accounting

carbon_compute.gms -- computes forestry stand carbon data

model_structure.gms

This file defines model structure and initially solves

include files:

model_scale.gms -- defines scaling factors for model

model_bounds.gms-- defines upper and lower bounds for model

calc_fixregs.gms-- calculates regional incidence of types of production

model_update.gms—updates incidence of forest stands and ag crops

report_onerun.gms

This file does report writing on solutions

include files:

report_setup.gms -- sets up parameters for a single run report

report_comparesetup.gms-- sets up parameters for a cross scenario report

report_agcal.gms -- computes single run agricultural report

report_forcal.gms -- computes single run forestry report

report_forresultsput.gms -- saves forestry report in put files

report_carboncal.gms -- computes single run GHG report

report_ghgtype.gms -- computes single run GHG report

report_comparecal.gms -- computes comparative run report

report_runsummarytables.gms -- computes cross run summary report

report_finalcal.gms -- displays cross scenario report

17.4 Flow Chart of Model Segments

Primary file	Secondary file that is included in primary file	File that is included in secondary file

allofit_fasom.gms	<	data_basicsets.gms	<<	data_fasomreg.gms
			<<	data_fasomreg.gms
			<<	data_fasomreg.gms
			<<	data_agsubreg.gms
			<<	data_agsubregtoreg.gms
	<	data_agprimary.gms		
	<	data_agsecondary.gms	<<	data_agfeeds.gms
	<	data_forproducts.gms		
	<	data_aginputname.gms		
	<	data_agcostname.gms		
	<	data_ghgtype.gms		
	<	data_agprocessset.gms	<<	data_agfeedprocess.gms
	<	data_ghg.gms	<<	data_ghgtype.gms
	<	data_forall.gms	<<	data_forproducts.gms
			<<	data_forinvent.gms
			<<	data_forexist.gms
			<<	data_forexistpc.gms
			<<	data_fornew.gms
			<<	data_fornewpc.gms
			<<	data_fornewcost.gms
			<<	data_forexistcost.gms
			<<	data_forminiharv.gms
			<<	data_forrotationage.gms
			<<	data_forfuelusage.gms
			<<	data_forsticky.gms
			<<	Data_forsupdem.gms
			<<	data_forlogsupdem.gms
			<<	data_forcapacity.gms
			<<	data_formcoefs.gms
			<<	data_forcanval.gms
			<<	Data_forRecycle.gms
	<	data_agall.gms	<<	data_agprimary.gms
			<<	data_agsecondary.gms
			<<	data_agfeeds.gms
			<<	data_agfeeds.gms

<< data_agcostname.gms
<< data_aginputname.gms
<< data_agprocessset.gms
<< data_agfeedprocess.gms
<< data_agfeedprocess.gms
<< data_agsupdem.gms
<< data_aginputprice.gms
<< data_agcropmix.gms
<< data_agnatmix.gms
<< data_agresource.gms
<< data_agcropbudsoil.gms
<< calc_fixregs.gms
<< data_aglivebuds.gms
<< data_agprocess.gms
<< data_agprocessregional.gms
<< data_agtransport.gms
<< data_agbiomass.gms
<< data_agmisc.gms
<< data_agghgmitigate.gms
<< data_agelectricemit.gms
<< data_agghglivestock.gms
<< data_agghgreglivestock.gms
<< data_agghgsoil.gms
<< data_agcemission_rawdata.gms
<< data_agsoilcarb.gms
<< data_agghgnonco2.gms
<< calc_agcondition.gms
<< calc_agliveghg.gms
<< data_agdynamic.gms

< calc_fixregs.gms
< data_landtransfer.gms

<< data_forconvert.gms
<< data_fordevelopment.gms
<< data_agdevelopment.gms

< policy_model.gms
< model_seperable.gms

	< calc_agsetup.gms		
	< model_setup.gms	<<	model_update.gms
	< model_update.gms		
	< calc_aggregate.gms		
	< data_carbon_trees.gms	<<	data_carbon_weightbyrpaland.csv
		<<	data_carbon_biomassmodel.csv
		<<	data_carbon_undercwd.csv
	< carbon_compute.gms		
model_structure.gms	< model_scale.gms		
	< model_bounds.gms		
	< calc_fixregs.gms		
	< model_update.gms		
report_onerun.gms	< report_setup.gms		
	< report_comparesetup.gms		
	< report_agcal.gms		
	< report_forcal.gms		
	< report_forresultsput.gms		
	< report_carboncal.gms		
	< report_ghgtype.gms		
	< report_comparecal.gms		
	< report_runsummarytables.gms		
	< report_finalcal.gms		

SECTION 6: FASOMGHG APPLICATIONS AND FUTURE PLANS

18 CHAPTER 17 VALIDATION

19 CHAPTER 18 POLICY APPLICATIONS

A core objective of FASOMGHG is to provide a tool for simulating the effects of various policy scenarios on a wide range of economic and environmental outcomes in the US forest and agricultural sectors. This section provides an overview of the types of policies that can be addressed by FASOMGHG, the basic procedures to follow to analyze policies using the model, and examples of policy-relevant studies that have been or could be performed using the model.

19.1 Types of policies and problems that can be evaluated using FASOMGHG

At its inception as FASOM, the primary focus of the modeling system was to evaluate carbon sequestration policies in the US forest and agricultural sectors to support wide-ranging assessments of climate change mitigation strategies. As the model has evolved to FASOMGHG, it provides a more complete assessment of GHG mitigation options in forestry and, in particular, agriculture. Moreover, the model is well-suited to work via integration with other models to assess the impacts of climate change on forestry and agriculture. Therefore, the relevance for GHG and climate policy has become even stronger. However, because of its breadth of coverage and depth of sectoral detail, FASOMGHG can be used to evaluate a wide range of policy issues other than GHGs and climate change. Indeed, most any type of policy affecting resource use or terms of trade in forestry and agriculture can, in principle, be evaluated by the model. Such examples may include trade policy, non-climate environmental policy, technical change, and resource conservation issues.

Table 18-1 includes a list of selected publications addressing various policy issues with FASOMGHG or its predecessor FASOM. The list does not include the numerous policy applications using ASMGHG or ASM. For a more complete and periodically updated references to related publications and policy applications of FASOMGHG and ASMGHG, consult Dr. B.A. McCarl’s website (http://agecon2.tamu.edu/people/faculty/mccarl-bruce/).

Table 18.1 Selected Policy Applications of FASOM or FASOMGHG

Policies analyzed	Publication
GHG Mitigation	
	Lee, H-C, B.A. McCarl, D. Gillig, and B. Murray. Forthcoming. "US Agriculture and Forestry Greenhouse Mitigation Over Time." In *Rural Lands, Agriculture and Climate beyond 2015: Usage and Management Responses,* F. Brouwer and B.A. McCarl (eds.), Dordrect, The Netherlands: Kluwer Academic Publishers.
	Gillig, D., B.A. McCarl, and R.D. Sands, "Integrating Agricultural and Forestry GHG Mitigation Response into General Economy Frameworks: Developing a Family of Response Functions," *Mitigation and Adaptation Strategies for Global Change,* vol. 9,iss. 3(July), pp. 241-259, 2004.
	Murray, B.C., B.A. McCarl, and H-C. Lee, "Estimating Leakage From Forest Carbon Sequestration Programs," *Land Economics*, 80(1), 109-124, 2004.
	Murray, B.C. and B.A. McCarl, *US Potential for increasing forest Carbon sinks above business-as-usual scenarios: an economic analysis,* Prepared for the Inter-Agency working group on land use and forest sinks, under the direction of the US Environmental Protection Agency, 2000.
	Adams, D.M., R.J. Alig., B.A. McCarl, J.M. Callaway and S.M. Winnett, "Minimum Cost Strategies for Sequestering Carbon in Forests", *Land Economics*, 75(3), 360-374, 1999.
	Alig, R.J., D.M. Adams, B.A. McCarl, and Haynes, R.W., "Evaluation of Effects of Forestry and Agricultural Policies on Forest Carbon and Markets", in S. Fox, and R.A. Mickler (eds) Chapter 41 of *The Productivity and Sustainability of Southern Forest Ecosystems in a Changing Environment*, Springer : New York, 1998, pp 755-776
	Alig, R.J., D.M. Adams, B.A. McCarl, J.M. Callaway, and S.M. Winnett, "Assessing Effects of Mitigation Strategies for Global Climate Change Within an Intertemporal Model of the US Forest and Agriculture Sectors", *Environment and Resource Economics*,9: 259-274 1997
Climate Change Impacts and Adaptation	
	Alig, R.J., D.M. Adams, and B.A. McCarl, "Projecting Impacts of Global Climate Change on the US Forest and Agriculture Sectors and Carbon Budgets," *Forest Ecology and Management*, 169, 3-14, 2003.
	Reilly, J.M., J. Hrubovcak, J. Graham, D.G. Abler, R. Darwin, S.E. Hollinger, R.C. Izaurralde, S. Jagtap, J.W. Jones, J. Kimble, B.A. McCarl, L.O. Mearns, D.S. Ojima, E.A. Paul, K. Paustian, S.J. Riha, N.J. Rosenberg, C. Rosenzweig, and F. Tubiello, *Changing Climate and Changing Agriculture: Report of the Agricultural Sector Assessment Team, US National Assessment,* prepared as part of USGCRP National Assessment of Climate Variability, Cambridge University Press, 2002.

(Was this FASOM or ASM?)

Irland, L. C., D.M. Adams, R.J. Alig, C. J. Betz, C.C. Chen, M. Hutchins, B.A. McCarl, K. Skog and B. L. Sohngen, "Assessing Socioeconomic Impacts of Climate Change on U. S. Forests, Wood-Product Markets and Forest Recreation", *BioScience*, 51(9) September, 753-764, 2001.

McCarl, B.A., D.M. Burton, D.M. Adams, R.J. Alig and C.C. Chen, "Effects of Global Climate Change on the US Forest Sector: Response Functions Derived from a Dynamic Resource and Market Simulator", *Climate Research*, 15(3), 195-205, 2000.

McCarl, B.A., D. Burton, D.M. Adams, and R.J. Alig, "Economic Dimensions of Climate Change Impacts on Southern Forests", in S. Fox, and R.A. Mickler (eds) Chapter 42 of *The Productivity and Sustainability of Southern Forest Ecosystems in a Changing Environment,* Springer: New York, 1998 pp 777-794

General sector policies and trends

McCarl, B.A., D.M. Adams, R.J. Alig and J.T. Chmelik, "Analysis of Biomass Fueled Electrical Power plants: Implications in the Agricultural and Forestry Sectors", *Annals of Operations Research*, 94, 37-55, 2000.

Alig, R.J., B.A. McCarl, D.M. Adams and P.J. Ince, "Economic Potential of Short-Rotation Woody Crops on Agricultural Land for Pulp Fiber Production in the United States", *Forest Products Journal*, April, 67-74, 2000.

Adams, D.M., R.J.Alig., B.A. McCarl, S.M. Winnett and J.M. Callaway, "The Effects of Factor Supply Assumptions on Intertemporal Timber Supply Behavior: The Cases of Investable Funds and Land", *Canadian Journal of Forest Research*, 28(2), 239-47, 1998.

Alig R.J., D.M. Adams and B.A. McCarl, "Ecological and Economic Impacts of Forest Policies: Interactions Across Forestry and Agriculture", *Ecological Economics*, 27, 63-78, 1998.

Alig, R.J., D.M. Adams and B.A. McCarl, "Impacts of Incorporating Land Exchanges Between Forestry and Agriculture in Sector Models", *Journal of Agricultural and Applied Economics*, 30(2), 389-401, 1998.

Adams, D.M., R.J. Alig, B.A. McCarl, J.M. Callaway and S.M. Winnett, "An Analysis of the Impacts of Public Timber Harvest Policies on Private Forest Management in the US ", *Forest Science*, 42(3), 343-358, 1996

The following subsections briefly review the types of policies that the model can be used to examine.

19.2 Climate Analysis

Climate policy is a major driver behind the development of FASOMGHG. The model is unique in its ability to combine data and models of GHG emissions and sequestration with data and models of economic activity in the US forest and agricultural sectors. This provides an integrated view of the joint GHG and economic effects of climate scenarios, economic policies, and combinations thereof.

Climate policy is oft divided into distinct elements: impacts, adaptation, and mitigation. The IPCC followed this taxonomy in developing their Third Assessment Report (IPCC 2001), with separate documents for (1) Mitigation, and (2) Impacts, Vulnerability, and Adaptation. FASOMGHG can be used to address these basic elements if climate policy, as described below.

19.2.1 GHG Mitigation

As indicated above, the original impetus for FASOM was to evaluate carbon sequestration in from land use change between agriculture and forestry and changes in forest management practices. By keeping carbon accounts across the landscape, the model can quantify the amount of carbon sequestered (stored) in forest and agricultural ecosystems under both baseline (business-as-usual) conditions and under specific policies to induce additional sequestration. The difference in carbon sequestered with the policies and without the policies (baseline) can be viewed as a measure of GHG mitigation within these sectors.

However, as has been described throughout the detailed chapters on model structure and data, FASOM's evolution to FASOMGHG has substantially expanded the model's ability to examine GHG mitigation strategies in forestry and agriculture. FASOMGHG enhancements (since the original version of FASOM) include the following

- Carbon sequestration in agriculture
- Fossil fuel mitigation through agricultural practices
- Mitigation of non-CO2 GHGs from agriculture
- Biofuel offsets

Thus, the model has evolved from one which specialized primarily in carbon sequestration through land use change and forestry to one that provides more comprehensive coverage of GHG mitigation in forestry and agriculture. Table 18-2 identifies the model's coverage of broad mitigation strategies, specific activities, and targeted gases.

Table 18-2: Broad GHG Mitigation Strategies Covered in FASOMGHG

Strategy	Mitigation Activities Tracked in FASOMGHG	Target GHG
Afforestation	Convert agricultural lands to forest	CO_2
Forest management	Lengthen timber harvest rotation Increase forest management intensity Forest preservation Avoid deforestation	CO_2
Agricultural soil carbon sequestration	Crop tillage change Crop mix change Crop fertilization change Grassland conversion	CO_2
Fossil fuel mitigation from crop production	Crop tillage change Crop mix change Crop input change Irrigated/dry land mix change	CO_2
Agricultural CH_4 and N_2O mitigation	Crop tillage change Crop mix change Crop input change Irrigated/dry land mix change Enteric fermentation control Livestock herd size change Livestock system change Manure management Rice acreage change	CH_4 N_2O
Biofuel offsets	Produce crops for biofuel use	CO_2

The coverage and structure of the model provides analytical capabilities to address the following policy questions

- What will be the net emissions of GHGs from US forestry and agriculture over time if no mitigation policies are put in place (business-as-usual)?
- How much GHG mitigation can be generated by the US forest and agricultural sectors if various economic incentives are put in place?
- What strategies and gases have the highest mitigation potential and lowest costs?
- How are GHG mitigation opportunities distributed across regions?
- How do GHG reductions from mitigation actions change over time, especially given the potential for re-releases of carbon sequestered in forests and soils?
- What are the direct and indirect consequences of mitigation policies that are limited in their coverage of activities, regions, or time periods? Indirect consequences could include leakage or reversal of GHG reduction benefits.

- How will changes in land use and management brought about by a GHG mitigation incentive program affect the production and prices of forest and agricultural commodities?
- How will changes in commodity production and prices affect the welfare of commodity producers and consumers?
- What ancillary (non-GHG) environmental effects (e.g., water quality, habitat) could occur as a result of GHG mitigation actions on the landscape? Are these *co-benefits* or *ancillary costs* of mitigation strategies?

Table 18-1 provides some examples of publications using FASOM or FASOMGHG to address GHG mitigation policy issues such as those raised above.

Examples of the type and nature of mitigation results that can be produced are presented below. These examples draw from a common set of analytic scenarios imposed on FASOMGHG that simulate responses to a hypothetical prices offered for GHG mitigation. Such a system could be viewed as part of an emissions trading mechanism for GHGs, though no such system currently exists, Responses are evaluated at GHG prices ranging from $1-50 per tonne of CO_2 equivalent.

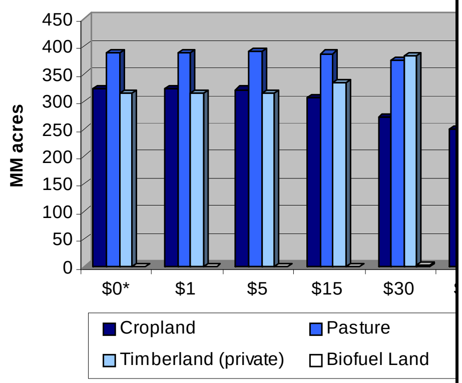
[note: I am pasting in results from the yet unpublished EPA Assessment Report here. If this report gets published, we should cite accordingly. If it does not, then we should perhaps set up the scenarios here and present them here as the only published outlet]

19.2.1.1 Land Use Projection

Figure 18-1 depicts how FASOMGHG projects land allocation across major groups in 2025 under the baseline scenario (price of $0) and prices of $1, $5, $15, $30 and $50 per tonne CO_2. The figure suggests that land use effects in 2025 are small except at prices greater than $15.

Figure 18-1

Land Use in 2025 at Different GHG Price Levels



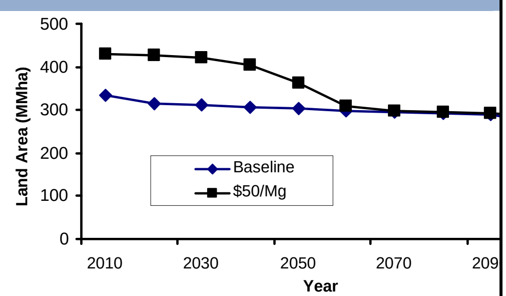
*Baseline

Notes: $ represent price per tonne, CO_2 Eq. Quantities are in million acres.

Figure 18-2 shows how one land use, timberland, changes over time at a relatively high GHG price ($50 per tonne). In this simulation, the initial rise in timberland reverts to baseline levels after several time periods. The commodity market feedbacks and other technological factors drive this land use reversion.

Figure 18-2

Timberland Area over Time: $50/t CO_2 Eq. vs. Baseline

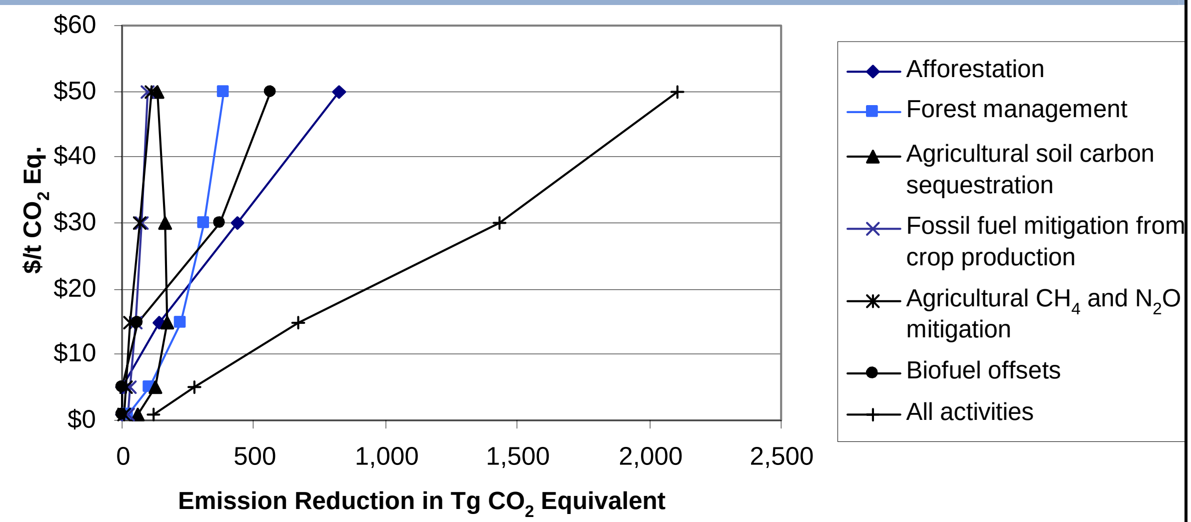


19.2.1.2 GHG Mitigation Supply Function

In economics, a supply function conveys the relationship between the price of a good and the quantity that is supplied. In this case, the good in question is GHG mitigation and the price is the price per tonne of mitigated GHG. Figure 18-3 shows this relationship over the $1-50 per tonne CO_2 price range. The supply function is decomposed into the broad mitigation strategies identified in Table 18-2. We see here that different strategies dominate at different prices.

GHG Mitigation Supply Function from National GHG Mitigation Totals by Activity

Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized over the time period 2010--2110.



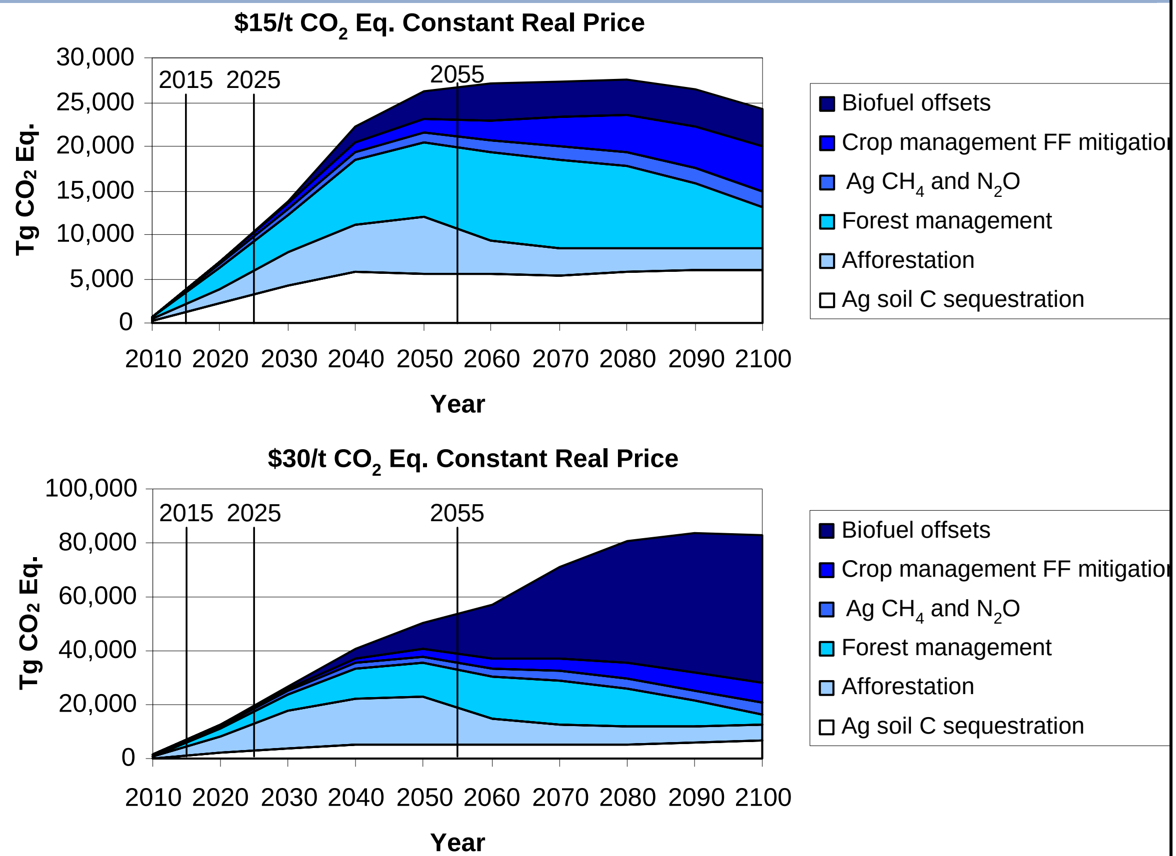
19.2.1.3 Cumulative Mitigation over Time

It is important to see how mitigation may vary over time, as policy targets and other factors may vary as well. Figure 18-4 tracks the cumulative total of mitigation quantity from the time the policy is implemented (in this case, the Year 2010) on out for 100 years at two different GHG prices. Inspection of the figure shows that the cumulative effect of forest carbon sequestration options (afforestation and forest management) rises at first and then falls, as the carbon sequestered in the initial years is later released through harvesting and land use change.

Figure 18-4

Cumulative GHG Mitigation over Time

Quantities are Tg CO_2 Eq. cumulative net emissions reduction below baseline.



19.2.1.4 Targeting Activities and Regions

The regional distribution of GHG mitigation opportunities may have important policy implications for legislators and developers of policies targeted to increase GHG mitigation in forestry and agriculture. For a variety of reasons, mitigation programs may need to be more limited in scope than one that pays for all mitigation activities and all gases. Consequently, it may be useful for policy targeting to use FASOMGHG to generate rankings of the top mitigation options by region-activity combination as indicated in Table 18-3.

Table 18-2: GHG Mitigation Quantity Ranking by Region--Activity Combination: Ranks are Based on Mitigation Quantities Annualized Over the Period 2010--2110

		GHG Constant Price Scenario ($/t CO_2 Eq.)				
Region	Activities	$1	$5	$15	$30	$50
SC	Forest management	1	1	1	3	3
CB	Agricultural soil carbon sequestration	2	2	4	7	10
LS	Agricultural soil carbon sequestration	3	3	6		
GP	Agricultural soil carbon sequestration	4	5	7		
SW	Fossil fuel mitigation from crop production	5	7			
RM	Agricultural soil carbon sequestration	6	8			
SC	Fossil fuel mitigation from crop production	7	6	8	10	
NE	Agricultural soil carbon sequestration	8	9			
CB	Fossil fuel mitigation from crop production	9	10			
CB	Agricultural CH_4 and N_2O mitigation	10				
SE	Forest management		4	3	6	8
SC	Afforestation			2	1	2
NE	Biofuel offsets			5	4	5
RM	Afforestation			9		
SW	Agricultural soil carbon sequestration			10		
CB	Afforestation				2	1
SE	Biofuel offsets				5	4
SC	Biofuel offsets				8	6
CB	Biofuel offsets				9	7
LS	Afforestation					9

19.2.2 Climate Change Impacts and Adaptation

The model's forest and agricultural sector activity and outcomes are driven by the biophysical productivity of the landscape. The economic returns to a particular land use or management practices are driven by the physical yields that can be generated. Clearly, climate is a significant factor in determining these yields in both the forest and agricultural sectors. For instance, geo-specific changes in temperature, precipitation, and CO2 concentrations over time (the "greenhouse effect") can affect the level and distribution of forest and agricultural yield potential. FASOMGHG can simulate farmers and foresters *adapt* to these climate-driven yield changes in yield by altering land uses and management practices. Accounting for these adaptations, the model can show how changes in climate ultimately impact the economic well-being of producers and consumers' in the forest and agricultural sectors.

In order for FASOMGHG to simulate future climate change scenarios, it must be integrated into a broader framework that includes global circulation models (GCM's) that project future climate change and biophysical models that translate climate change to yield changes in forestry and agriculture. Such an integration was performed as part of the US National Assessment Synthesis Team (2001) report analyzing possible climate change impacts on forestry, agriculture and other sectors, wherein FASOM was linked with GCM model scenarios from the Hadley Centre (UK) and The Canadian Centre climate models and corresponding simulations from biophysical models such as Century (Parton, 1996) and TEM (Melillo et al 1993).

The NAST analyses showed how future climate change scenarios could affect aggregate productivity of US forests and agricultural lands, thereby affect resource allocation across and within the sectors, i.e., adaptations such as land use change, crops planted, and changes in management practices. The climate-induced changes and the adaptations they engender have economic consequences for the sectors in question, affecting the levels of output and prices for timber and agricultural commodities and the welfare of producers and consumers' in these sectors. For example, climate change impacts on the forest sector are reported for the FASOM scenarios run for the NAST report in Irland et al (2001). Under scenarios showing a climate change-induced increase in aggregate forest productivity, timber output rises, prices fall, consumers' are made better off and producers are made worse off. FASOMGHG can show how these effects vary by region within the US, by climate scenario (Hadley or Canadian) and by biophysical model employed for gauging productivity effects (Century or TEM).

Insert figures here from NAST Ch. 17, Fig 8 and 9 or something like that? (http://www.usgcrp.gov/usgcrp/Library/nationalassessment/17Forests.pdf)

19.3 General Land Use, Forest, and Agricultural Policies and Trends

There is a long history of policies operating at the US national and regional levels that try to modify the way land is used, encourage certain management practices, set targets for commodity production levels, and achieve other environmental, economic, and social policy objectives. FASOMGHG's broad coverage and sectoral detail make it useful for examining a wide range of these policies. Policy options are evaluated in term below.

19.3.1 Land Use

The inclusion of land allocation mechanisms in FASOMGHG allows for exploration of land allocation responses to changes in policy, market, or other conditions. Some of the subjects for analysis have included or could include

- Tree planting on marginal agricultural lands
- Grassland conversion
- Effect of urbanization on land use and commodity production
- Land use response to technological and environmental change

- Zoning and other land use restrictions at the regional level

As an example, Alig et al (1997) found that a policy targeting the conversion of roughly 5 million acres of agricultural land to forest without offering counter-incentives (or disincentives) for keeping land in forest, caused a substantial shifting of land from forest back to agriculture. [Bruce or Ralph, please check and see if I got this right. Its been a while BCM}

19.3.2 Forest sector

The analytical framework and data of FASOMGHG allow it to explore a variety of resource allocation and policy issues in the forest sector including

- Private forest management incentives
- Forest conservation/preservation
- Variations in allowable timber harvests on public lands
- Wood products trade policy between US and Canada
- Effects of advances in technology, such as genetic improvements in forest stock
- Expanded use of management practices to reduce fire risks (e.g., thinning)
- Land transfers between owner groups (forest industry, nonindustrial private, public)

For example, FASOMGHG has been used to examine how recent technical advances in short rotation forestry might effect the level, price, and regional distribution of pulpwood timber harvests and corresponding land use responses (Alig et al 2000). Additionally, the model has been used to examine interregional land allocation and forest management responses to region-specific public timber harvest policies (Adams et al 1996, Murray et al 2004).

19.3.3 Agricultural sector

US agricultural policy is far-reaching and has many dimensions. Much agricultural policy is encompassed in periodic revisions of the Farm Bill and its many provisions affecting commodity support programs, conservation, environmental protection, and rural income support. Specific aspects to consider in agricultural sector policy analysis may be

- Conservation/land retirement programs such as the Conservation Reserve Program (CRP)
- Programs to enhance environmental quality and sustainable development in agriculture (e.g., EQUIP)
- Commodity loan programs

- Commodity promotion programs
- Technological change in agriculture
- Genetic improvements in seed stock
- Water use restrictions
- Agricultural trade policy
- Environmental regulations in agricultural production

[FASOM pubs haven't spoken to these issues per se. Unless the following is based on FASOM … Callaway, J.M. and B.A. McCarl, "The Economic Consequences of Substituting Carbon for Crop Subsidies in United States' Agriculture", *Environmental and Resource Economics*, 7,15-43, 1996]

19.3.4 Bio-Energy Analysis

Although biofuel production is typically considered part of a GHG mitigation strategy, it can also be considered a component of energy policy. As a renewable resource, biofuels have attracted attention as a potentially sustainable source of energy supply. FASOMGHG incorporates the costs of biofuel production and the size of subsidy necessary for it to out compete conventional fossil fuels. Studies such as McCarl et al (2000) have used FASOMGHG to estimate the economic potential for biofuel production in the agricultural and forest sectors to meet growing energy demands.

[more here]

20 CHAPTER 18 UNCERTAINTIES, CAVEATS, AND FUTURE PLANS

(McCarl and Adams)

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SECTION 8: APPENDICES

21 APPENDIX: GLOSSARY OF FORESTRY TERMS

Afforestation The establishment of a forest or stand in an area where the preceding vegetation or land use was not forest.

Age cohort An interval into which the age range of trees is divided for classification or use. Five year intervals are used.

Crop land -- Land used for the production of adapted crops for harvest, including row crops, small grain crops, hay crops, nursery crops, orchard crops, and other specialty crops. The land may be used continuously for these crops, or they may be grown in rotation with grasses and legumes.

Cull tree -- A live tree, 5.0-inches in diameter at breast height (d.b.h.) or larger, that is unmerchantable for sawlogs now or prospectively because of rot, roughness, or species. (See definitions for rotten and rough trees).

Diameter class -- A classification of trees based on diameter outside bark measured at breast height (4 1/2 feet above ground). The common abbreviation for "diameter at breast height" is d.b.h. With 2-inch diameter classes, the 6-inch class, for example, includes trees 5.0 through 6.9 inches d.b.h.

Douglas-fir subregion -- The area in the states of Oregon and Washington that is west of the crest of the Cascade Range (also called Pacific Northwest Westside).

Farmer-owned lands Lands owned by a person who operates a farm, either doing the work themselves or directly supervising the work.

Fiber products -- Products made with largely intact plant fibers (or wood fibers) derived primarily from pulpwood, pulpwood chips, and recovered paper, such as wood pulp, paper or paperboard products, and also (in this publication) products made primarily from pulpwood roundwood, such as oriented strand board, but not including other panel products made primarily from fine wood residues, sawdust or bark.

Forest industry (FI) -- A diverse group of manufacturers that harvest, process, and use timber products in their final products. Activities include the harvesting of the timber resource; conversion of logs to primary timber products, such as lumber, plywood, and wood pulp; and the conversion of primary timber products to secondary or final products, such as pallets, furniture, and paper products.

Forest land -- Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10 percent stocked with forest trees, and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West, and afforested areas. The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a minimum crown width of 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet in width.

Forest management type A classification of timberland based on the species and source of trees forming a plurality of live trees present.

Forest Inventory and Analysis (FIA) Regional forest survey units of the USDA Forest Service. See Smith et al. (2001) for examples of the types of data collected and compiled.

Forest inventory types A classification of forest land based on the species forming a plurality of the live-tree stocking. Major forest type groups recognized in the timber assessment include:

Natural pine A southern management type representing stands that (a) have not been artificially regenerated, (b) are classed as a pine or other softwood forest type, and in which 50 percent or more of the naturally established stand is loblolly pine, slash pine, shortleaf pine, longleaf pine, or other southern pines singly or in combination. Common associates include oak, hickory, and gum.

Planted pine A southern management type representing forests in which 50 percent or more of the stand is loblolly pine, slash pine, shortleaf pine, longleaf pine, or other southern pines that have been established by planting or direct seeding.

Lowland hardwoods (bottomland hardwoods) -- A southern management type composed of forests in which 50 percent or more of the stand is tupelo, blackgum, sweetgum, oak, and southern cypress, singly or in combination, and southern pine makes up less than 25 percent. Common associates include cottonwood, willow, oak, elm, hackberry, and maple. This type is found on the alluvial flood plains of the Mississippi and other southern rivers. May also be called bottomland hardwood.

Oak-pine A southern management type composed of forests in which 50 percent or more of the stand is hardwood, usually upland oaks, and southern pines make up 25 to 49 percent of the stocking. Common associates include upland oak-shortleaf pine in the foothills and plateaus; mixed hardwood-loblolly pine on moist sites; and scrub oak-longleaf pine in the sand hills of the Carolinas, Georgia, and Florida. Other associates include gum, hickory, and yellow-poplar. May also be called mixed pine-hardwood.

Douglas-fir -- Forests in which Douglas-fir composes a plurality of the stocking. Common associates include western hemlock, western redcedar, the true firs, redwood, ponderosa pine, and larch.

Hemlock-Sitka spruce -- Forests in which western hemlock, Sitka spruce, or both compose a plurality of the stocking. Common associates include Douglas-fir, silver fir, and western redcedar.

Upland hardwoods -- A southern management type composed of stands that have at least 10 percent stocking and classed as an oak-hickory or maple-beech-birch forest type. Common associates include yellow-poplar, elm, maple, and black walnut.

Fuelwood -- Wood used by conversion to some form of energy, primarily residential use.

Growing stock -- A classification of timber inventory that includes live trees of commercial species meeting specified standards of quality or vigor. Cull trees are excluded. When associated with volume, includes only trees 5.0 inches d.b.h. and larger.

Hardwood -- A dicotyledonous (nonconiferous) tree, usually broad leaved and deciduous.

Harvest (a) An intermediate or final cutting that extracts salable trees. (b) The volume of roundwood harvested from both growing-stock and nongrowing-stock sources that is extracted from harvest sites.

Highly erodible crop land -- All crop land in land capability classes (classifications used by the Soil Conservation Service to rate the suitability of soils for agricultural production) 3e, 4e, 6e, and 7e.

Industrial wood -- All commercial roundwood products except fuelwood.

Land area -- (a) Bureau of the Census: The area of dry land and land temporarily or partly covered by water, such as marshes, swamps, and river food plains; streams, sloughs, estuaries, and canals less than 1/8 statute mile wide; and lakes, reservoirs, and ponds less than 40 acres in area. (b) Forest Inventory and Analysis: same as (a) except that the minimum width of streams, etc., is 120 feet, and the minimum size of lakes, etc., is 1 acre. This latter definition is the one used in the forest sector work.

Live cull -- A classification that includes live, cull trees. When associated with volume, it is the net volume in live, cull trees that are 5.0 inches d.b.h. and larger.

Logging residues -- The unused portions of growing-stock trees cut or killed by logging and left in the woods.

Managed plantations -- Stands of trees established by artificial means (e.g., planting or direct seeding) composed primarily of single or related species, treated to have uniform structure and age class, and projected to receive at least minimal treatment for growth enhancement.

Management intensities -- Timber growth and yield catagories developed to represent the development of stands under various improved management practices (i.e., genetic improvement, stocking control, fertilization, commercial thins, etc.).

Net annual growth -- The average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year, and minus the net volume of trees that became cull trees during the year.

Net volume in cubic feet -- The gross volume in cubic feet less deductions for rot, roughness, and poor form. Volume is computed for the central stem from a 1-foot tall stump to a minimum 4.0-inch top diameter outside bark, or to the point where the central stem breaks into limbs.

Nonforest land -- Land that has never supported forests and lands formerly forested where use of timber management is precluded by development for other uses. (Note: Includes area used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide, and clearings, etc., more than 1 acre in size, to qualify as nonforest land).

Nongrowing stock -- A classification of inventory that includes all trees not meeting the standards for growing stock.

Nonindustrial private forest (NIPF) -- An ownership class of private forest lands whose owner does not primarily operate wood-using plants (distinguished from land owned by forest industry).

Nonsawtimber timber -- Timber that is not used by sawmills or veneer mills, but is used in the manufacture of pulp, paper, OSB, various nonstructural panels, or used for fuelwood.

Nonstocked areas -- Timberland less than 10 percent stocked with growing-stock trees.

Oriented strand board (OSB) -- An engineered structural-use panel made from wood strands that are cut longitudinally from small-diameter logs or pulpwood roundwood. The strands have a high length-to-thickness ratio and are bonded together with waterproof resin under heat and pressure. The strands are oriented along the length or width of the panel in alternating layers to take advantage of the inherent longitudinal fiber strength of wood. The panels are used in construction for roof, wall, and floor sheathing and for the web for prefabricated wood I-joists.

Other forest land -- Forest land other than timberland and productive reserved forest land. It includes reserved forest land, and available land that is incapable of producing annually 20 cubic feet per acre of industrial wood under natural conditions because of adverse site conditions such as sterile soils, dry climate, poor drainage, high elevation, steepness, or rockiness. Urban forest land is also included that, owing to its location, is considered unavailable for sustained timber harvesting.

Other land -- Nonforest land less the area in streams, sloughs, estuaries, and canals between 120 and 660 feet and lakes, reservoirs, and ponds between 1 and 40 acres in area (i.e., nonforest land less non-Census water area).

Other removals -- Unutilized wood volume from cut or otherwise killed growing stock, from cultural operations such as precommercial thinnings, or from timberland clearing. Does not include volume removed from inventory through reclassification of timberland to productive reserved timberland.

Other sources -- Sources of roundwood products that are nongrowing stock. These include salvable dead trees, rough and rotten trees, trees of noncommercial species, trees less than 5.0 inches d.b.h., tops, and roundwood harvested from nonforest land (e.g., fence rows).

Ownership -- Categories of property owners: a combination of persons; a legal entity such as a corporation, partnership, club, or trust; or a public agency. All parcels of land in the US are assigned to one of the categories of ownership.

Plantation -- See managed plantation.

Poletimber -- Live trees at least 5.0 inches in diameter, but smaller than sawtimber trees (9.0 inches or greater).

Ponderosa pine subregion -- The area in the states of Oregon and Washington that is east of the crest of the Cascade Range, (also called Pacific Northwest East).

Private Ownerships:

Forest industry (FI) -- An ownership class of private lands owned by companies that grow timber for industrial use and own wood processing facilities.

Nonindustrial private forest (NIPF) -- An ownership class of private lands where the owner does not operate wood-use plants. This includes lands owned by operators of farms, lands owned by private individuals, and lands owned by private corporations.

Native American-(a) Lands held in trust by the US or states for Native American tribes or individual Native Americans. (b) Lands owned in fee by Native American tribes whether subject to federal or state restrictions against alienation or not. Since 1990, these lands are grouped with other private lands in the NIPF ownership group.

Productivity class -- A classification of forest land in terms of potential annual cubic-foot volume growth per acre at culmination of mean annual increment in fully stocked natural stands.

Public ownerships:

Federal -- An ownership class of public lands owned by the US Government.

National forest -- An ownership class of federal lands, designated by Executive order or statute as national forests or purchase units, and other lands under the administration of the Forest Service including experimental areas and Bankhead-Jones Title III lands.

Other public -- An ownership class that includes all public lands except national forest. This category generally includes federal, state, county, and municipal ownerships.

Pulpwood -- Roundwood, wood chips, or wood residues that are the wood raw materials used for the production of wood pulp or the roundwood inputs for reconstituted panels (such as oriented strand board).

Reserved timberland -- Forest land withdrawn from timber use through statute, administrative regulation, or designation without regard to protective status.

Residues -- Bark and woody materials that are generated in primary wood-using mills when roundwood products are converted to other products. Examples are slabs, edgings, trimmings, miscuts, sawdust, shavings, veneer cores and clippings, and pulp screenings. Includes bark residues and wood residues (both coarse and fine materials) but excludes logging residues.

Removals -- The net volume of growing-stock trees removed from the inventory by harvesting; cultural operations, such as timber stand improvement or land clearing; or changes in land use.

Rotten tree -- A live tree of commercial species that does not contain a sawlog now or prospectively, primarily because of rot (i.e., when rot accounts for more than 50 percent of the total cull volume).

Rough tree -- (a) A live tree of commercial species that does not contain a sawlog now or prospectively, primarily because of roughness (i.e., a sound tree that is culled because of such factors as poor form, splits, or cracks affecting more than 50 percent of its total cull volume); or (b) a live tree of noncommercial species.

Roundwood -- Logs, bolts, or other round sections cut from growing-stock and nongrowing-stock sources such as trees smaller than 5.0 inches d.b.h.; stumps, tops, and limbs of growing stock trees; rough and rotten trees; dead trees; and trees that grow on land other than timberland.

Roundwood equivalent -- The volume of logs or other round products required to produce given quantities of lumber, plywood, wood pulp, paper, or other similar products, after deducting the proportion of wood raw material input that is obtained not from logs or roundwood but from plant byproducts or recycled wood fiber (from recovered paper).

Sawlog -- A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight, and with a minimum diameter inside bark of 6 inches for softwoods and 8 inches for hardwoods, or meeting other combinations of size and defect specified by regional standards. A log usually used in the manufacture of lumber and plywood.

Sawtimber -- Stands at least 10 percent occupied with growing-stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

Sawtimber trees -- Live trees containing at least one 12-foot saw log or two noncontiguous 8-foot logs, and meeting regional specifications for freedom from defect. Softwood trees must be at least 9.0 inches d.b.h., and hardwood trees must be at least 11.0 inches d.b.h.

Site productivity class -- A classification of forest lands in terms of inherent capacity to grow crops of industrial wood. The class identifies the average potential growth in cubic feet per acre per year and is based on the culmination of mean annual increment of fully stocked natural stands. An example for the South is given next.

High sites -- Land capable of growing at least 85 cubic feet of wood per acre per year.

Medium sites -- Land capable of growing 50 to 85 cubic feet of wood per acre per year.

Low sites -- Land capable of growing 20 to 49 cubic feet of wood per acre per year.

Softwood -- A coniferous tree, usually evergreen, having needles or scalelike leaves.

Stocking -- The degree of occupancy of land by trees, measured by basal area or number of trees by size and spacing, or both, compared to a stocking standard; i.e., the basal area or number of trees, or both, required to fully use the growth potential of the land.

Stumpage -- Standing timber (trees) in the forest.

Stumpage price -- The price paid for standing timber (trees) in the forest. Usually expressed as dollars per thousand board feet, log scale.

Succession -- A series of dynamic changes by which one community succeeds another through stages leading to potential natural community or climax. Forest type transition is a related but broader concept that includes the possibility of changes due to human influences, such as disturbances that can lead to different seral stages (Alig and Butler 2004).

Timber supplies -- The volumes of roundwood actually harvested, range of volume available for harvest at varying price levels, or future volumes estimated to be harvested at market equilibrium. Includes roundwood from growing-stock and nongrowing-stock sources.

Timberland -- Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber use by statute or administrative regulation. Areas qualifying as timberland have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.

Tops -- The wood of a tree above the merchantable height (or above the point on the stem 4.0-inches diameter outside bark [dob]). It includes the usable material in the uppermost stem and branches.

Unreserved forest land -- Forest land (timberland and woodland) that is not withdrawn from use by statute or administrative regulation. Includes forest lands that are not capable of producing in excess of 20 cubic feet per year of industrial wood in natural stands.

Urban and other areas -- Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; school yards; cemeteries; roads and railroads; airports; beaches, power lines, and other rights-of-way; or other nonforest land not included in any other specified land use class.

22 APPENDIX NATIONAL FOREST YIELDS

Existing and regenerated timber yield projections for National Forest aggregates were estimated using strata similar to those used in the private existing yield tables. Forest types were aggregated into softwood and hardwood groups, while all inventory with timber 90 years or older aggregated into an uppermost FASOMGHG age cohort. Yield projections are based on ATLAS modeling by Mills and Zhou (2003). Based on data limitations, each stand in the inventory was assigned a medium site class.

In the Southern regions, ATLAS was unable to project yields of older stands for the entire 100-year time horizon. In the older stands the total volume within the strata was used to extrapolate yield curves throughout the period. Fire management, along with other natural disturbances and forest management activities, and wildfire occurrence are implicit in the ATLAS yield curves.

Timber yield estimation for regenerated stands was also based on the ATLAS approach described by Mills and Zhou (2003). Mills and Zhou (2003) calculated regeneration failures by region, and used lagged yields to reflect failed cases. They had acres remain in the youngest timber age class for an extra five or ten-years. Lacking data on pre- and post-disturbance forest types, all regenerated stands returned to the same forest type from which they originated.