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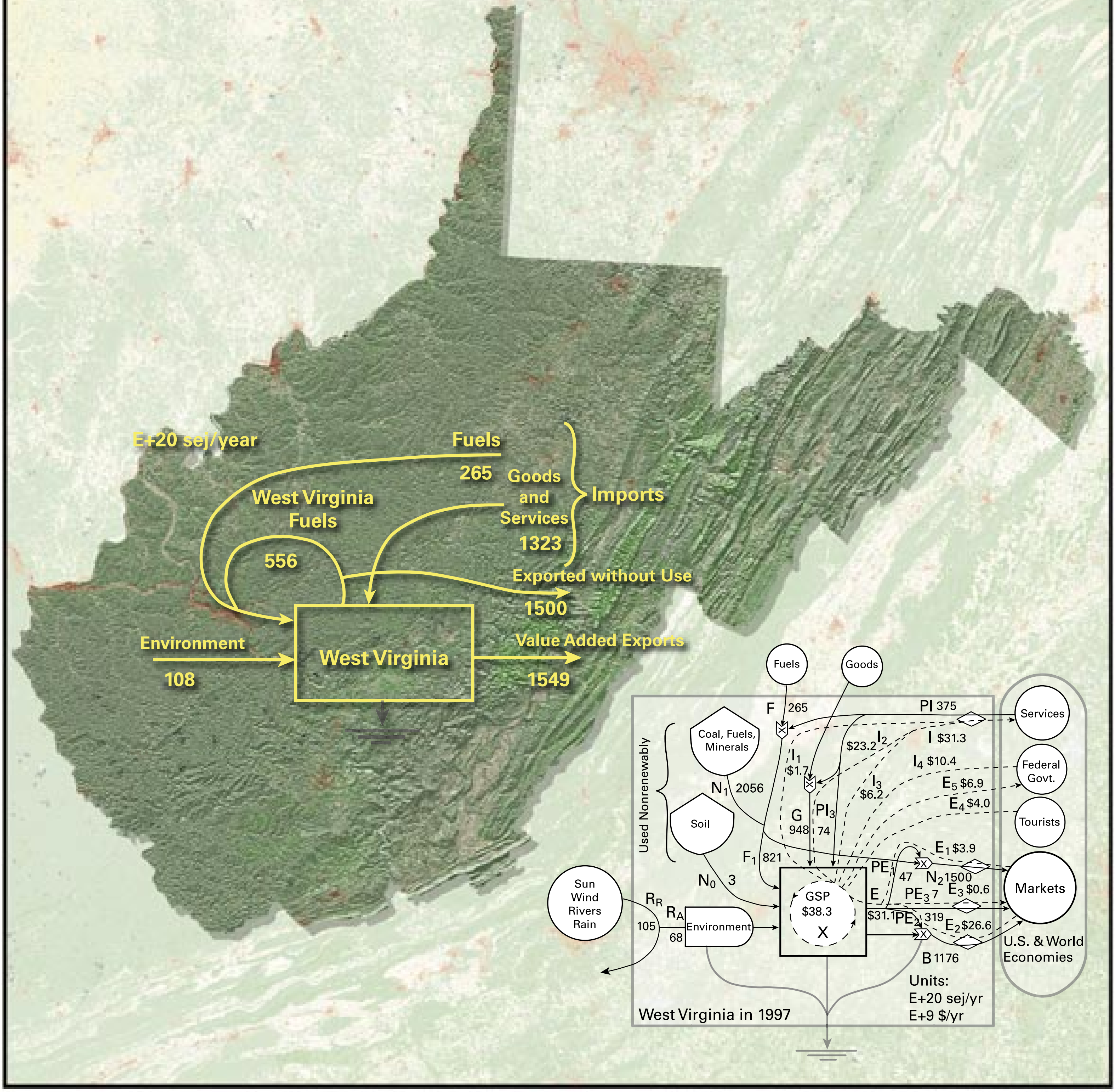
Environmental Accounting Using Emergy: Evaluation of the State of West Virginia



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Environmental Accounting Using Emergy: Evaluation of the State of West Virginia

Daniel E. Campbell
Sherry L. Brandt-Williams
USEPA, Office of Research and Development
National Health and Environmental Effects Research Laboratory
Atlantic Ecology Division, Narragansett, RI 02882

Maria E. A. Meisch
Dept. Environmental Engineering Sciences
University of North Carolina
Chapel Hill, NC

U.S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory
Atlantic Ecology Division
Narragansett, RI

NOTICE

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ABSTRACT

Historically, questions related to environmental policy have been difficult to solve, because solutions depend on accurately balancing the needs of both human and natural systems. In addition, there has been no good way to express the socioeconomic and environmental effects of policies in common terms. The USEPA has recognized that a knowledge gap exists in our ability to assess the effects of environmental policies using a comprehensive, integrated approach. Assessment methods that can bridge this gap are needed to address complex issues of environmental policy. Based on past studies, environmental accounting using emergy was identified as a method that had been used by some scientists to bridge the gap. This USEPA Project Report provides a guide to Emergy Analysis methods with particular emphasis on those methods used to characterize a state within the larger context of its region and the nation. An emergy evaluation of the State of West Virginia was performed as a case study to illustrate the method. The results of the West Virginia case study provided indices that were used to elucidate several questions that environmental managers asked about this state, when considering policy needs for the state as a whole. Assessment methods for quantifying imports and exports to and from states within the United States were further developed in this study. The Emergy Analysis of West Virginia documented the environmental and economic resource base for the state in common terms (*i.e.* solar emjoules) and the indicators derived from the emergy evaluation were used to examine questions of self-sufficiency, sustainability, the balance of exchange, and quality of life in the state as a whole. The results of this study may be useful to planners and managers who must perform analyses or recommend policy for the State of West Virginia. Also, scientists who need large scale indicators for the State as a context for studies focused on smaller scale systems (watersheds, counties, or industries) may find the results of this study useful. In addition, the general methods described here can be used to analyze other states within the United States and they may also serve as a starting point for emergy studies of large watersheds and regions.

Keywords: emergy methods, environmental accounting, West Virginia, renewable resources, nonrenewable resources, sustainability, quality of life, import-export balance

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PREFACE

PURPOSE OF THE REPORT

This USEPA Project Report has two purposes. The first purpose is to provide, as a peer-reviewed EPA report, a guide to Emergy Analysis methods with particular emphasis on those methods used to characterize a state within the larger context of its region and the nation. The second purpose is to present the results of a case study, an emergy evaluation of the State of West Virginia, and to examine the efficacy of this study's results in answering several questions that environmental managers asked about this state, when considering policy needs at the level of the state as a whole.

SIGNIFICANCE OF THE REPORT

Historically, questions related to environmental policy have been difficult to solve, because solutions depend on accurately balancing the needs of both human and natural systems and there has been no good way to express the socioeconomic and environmental effects of policies in common terms. The USEPA has recognized that this knowledge gap exists in our ability to assess the effects of environmental policies using a comprehensive, integrated approach. Assessment methods that can bridge this gap are needed to address complex issues of environmental policy. Based on past studies, environmental accounting using emergy was identified as a method that had been used by scientists to bridge the gap. In September of 2001 a joint project between the Canaan Valley Institute (CVI), a private nonprofit corporation headquartered in Thomas, WV and the USEPA's Office of Research and Development (ORD) was begun to assess the environmental, social, and economic system in West Virginia and to evaluate the integrated effects of environmental policies on multiple scales. In connection with this project, an emergy analysis of West Virginia was performed to give an overview of the state and to supply key indices needed for the analysis of watershed restoration in smaller scale systems of the state. The emergy analysis shown here is a product of this collaboration.

Economists often struggle to understand the concept of emergy and why we go to so much trouble to document economic and ecological flows and storages in these terms. The practical answer is that the accounts for environmental systems cannot be kept in dollars alone, because environmental systems are based on the work of both humanity, which is paid for by a counter flow of dollars, and the work of ecosystems, for which no money is paid. An accurate picture of environmental systems requires that we account for the flows and storages of energy, matter, and information that are responsible for supporting economic and social activities and that may not be accompanied by flows of money. Energy can be used as a common denominator for quantifying all these flows. Converting flows of energy to emergy puts the work done by the economy and the environment on the same scale, so that economic and environmental flows are directly comparable. While it is true that dollar values are directly comparable it is also true that economic markets only value a subset of the products and processes that are important in environmental systems. The key synthesis produced by Emergy Analysis is an accounting of social, economic and environmental flows in common terms on an objective basis. Thus for the first time what is removed from West Virginia is seen in true relationship to what is received in return. It is true that everyone in West Virginia realizes that coal is the basis for the West Virginia economy, but this is the first time the numbers have been calculated to show the relationship of the real wealth in coal to other economic and environmental flows. The importance of recognizing the true nature of value in exchanges is easily illustrated by the inequitable barter between Europeans and Native Americans where ecological resources, *e.g.*, animal skins, and land of great value were exchanged for trinkets. Emergy accounting can potentially give environmental managers tools similar to those regularly used by financial analysts to make business decisions. Further development of the analysis methods and tools presented in this report will make it possible for managers to first examine complete and commensurate economic and environmental accounting data before making policy decisions about environmental systems.

The State of West Virginia and its relationships with its region and the nation are characterized in a case study presented in this report. Insights from this study may be useful in establishing a context for determining policies for the state as a whole. However, finer scale analyses must be performed to address specific environmental management problems, such as determining the costs and benefits of watershed restoration. In addition, the analysis methods described here can be used as a guide to creating emergy accounts for any state in the United States.

STRUCTURE OF THE REPORT

This technical report gives an overview of the emergy accounting and analysis methodology, which can be used to evaluate environmental systems on any scale of organization (Odum 1996). However, it is impossible to condense the methods and insights of a comprehensive methodology in a single, relatively short document. For this reason, the Methods (Section 2) focuses on methods, calculations and data sources needed to evaluate a state within the United States of America. Even with this restriction, the task is daunting because there are 50 states and each one will present the researcher with new problems to solve. In this report we have made the task somewhat easier through the development of a method for determining the imports to and exports from any state using data from the U.S. Census Bureau’s Commodity Flow Survey. Application of the emergy analysis method is demonstrated through reporting a case study of the State of West Virginia (Section 3), which is presented in lieu of a Results section. Section 3 is written so that it can stand alone as a final report on the emergy analysis of West Virginia. Those readers who are primarily interested in the results of this study can go directly to Section 3.

The emergy analysis and environmental accounts for the State of West Virginia given in the case study include the following eight elements that we used to characterize the state: (1) a narrative history of the state, (2) a detailed energy systems diagram of the state as an environmental system with supporting tables, (3) the Emergy Income Statement showing annual emergy and dollar flows of renewable and nonrenewable resources, production, consumption, imports and exports, (4) the Emergy Balance Sheet showing some of the stored assets in the state, (5) an aggregate diagram giving a macroscopic overview of the energy resource base for the state’s economy and a summary table from which indices are calculated, (6) emergy indices of system structure and function, (7) the emergy signature for the state, and (8) the findings of the analysis applied to answer several questions formulated by environmental managers.

Following the Emergy Analysis of West Virginia, there is a Discussion (Section 4), which examines (1) refinements to the emergy accounting methods used for states, (2) quality assurances, the reliability of the data, and areas of uncertainty in the analysis, and (3) the use of emergy accounting data for environmental decision-making. A path for future research and development of the method is proposed and future research plans are mentioned. References are given in Section 5 and Section 6 lists the data sources used along with their Worldwide Web addresses. Extensive data and documentation to support the method and the case study are given in the appendices found in Section 7. These appendices are as follows: the Energy Systems Language (Appendix A), information on the transformities used in this report (Appendix B), notes documenting the energy and emergy calculations (Appendix C), import-export calculation methods (Appendix D), and emergy analysis tables for West Virginia in 2000 (Appendix E).

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Section 1

INTRODUCTION

Accurate accounting of the inflows, outflows and storages of energy, materials, and information is necessary to understand and manage environmental systems at all levels of hierarchical organization. The accounting tools, *i.e.*, the emergy income statement, emergy balance sheet, and emergy indices described in this document can be used to analyze and understand systems defined for any chosen set of boundaries. Boundaries of concern to us define an environmental system containing both ecological and socioeconomic components. The research or management questions asked at each level of organization will be somewhat different but the most important questions that are concerned with the overall condition of the system, will be illuminated by information and indices related to the inflows, outflows and storages of energy, matter, and information. In this report we present the methods of environmental accounting using emergy and apply them to analyze the State of West Virginia. Therefore, the particular sources of data and methods presented here will relate to the calculation of the important flows and storages for states within the United States.

At present, records for the environment are kept in terms of physical units such as pounds of chemical pollutants discharged, miles of degraded streams, or the number of endangered species present in a given area, while the accounts of human activities are for the most part kept in dollars. Neither accounting mechanism is able to address the credits and debits of the other, thus there is often a gap in the scientific assessment information given to managers faced with solving complex environmental problems that often have social, economic and ecological consequences. To keep accurate accounts for both the environment and the economy, it is obvious that we need a system capable of expressing the credits and debits (costs and benefits) that accrue to each in common terms. For more than 100 years, physical and social scientists have struggled with this problem, *i.e.*, how to incorporate resource limitations and contributions into the formulations of economics (Martinez-Alier, 1987). Land, labor, energy and other physical quantities have been tried without much success. Often these efforts centered on energy as a potentially unifying common denominator for accounting purposes because it is both required for all production processes and incorporated in all products of production. These early efforts failed largely because none of the proposed energy-based accounting methods considered differences in the ability to do work among energies of different kinds (Odum 1996).

In the 1980s, H.T. Odum and his colleagues solved this problem through the development of the concepts of emergy and transformity (Odum 1988). *Emergy* is the available energy of one kind previously used up directly and indirectly to make a product or service. The unit of emergy is the *emjoule*, which connotes the past use of energy that is embodied in the present product or service. *Transformity* is the emergy used to make a unit of available energy of the product or service. Most often, emergy accounts for the environment and the economy are kept using the solar joule as a base. In this case solar transformities are expressed as *solar emjoules* (sej) per joule (J). *Empower* is the flow of emergy (sej) per unit time. Emergy is related to the system of economic value through the emergy to money ratio. The *emdollar* (Em$) value of a flow or storage is its emergy divided by the emergy to money ratio for an economy in that year (Odum 1996). Odum's innovation established a medium for environmental accounting that for the first time made it possible to express economic commodities, services, and environmental work of all kinds on a common basis as emergy. In this report we use the methods of emergy accounting to demonstrate how keeping the books for environmental systems can help us identify problems and seek solutions at the macroscopic level of a state's economy. We adapted two standard accounting tools, the income statement and the balance sheet, to characterize the state's annual activities and long-term assets, respectively. We believe that creating emergy accounts for environmental systems is a method to bridge the gap between economic and ecological analyses of the effects of environmental policies.

Section 2

Methods

Emergy evaluations of the macroscopic features of an environmental system such as a state, region, or country are carried out in the same manner for each system regardless of its size or level in the hierarchy of organization, *e.g.*, county, state, nation, 1st, 2nd,..6th order watersheds, etc. Emergy analyses like other assessment methods are guided by the research or management questions of concern. In general, the hierarchical organization of ecological and economic systems requires that emergy accounts be created for more than one level of organization to obtain accurate answers to questions about a system at any particular level of organization. Multiple levels of organization are examined because large-scale patterns within a system are often determined by energy inflows from the next larger system, whereas, internal system dynamics may be affected by policy changes in the management of important subsystems. The examination of multiple levels of organization is also recommended because environmental policies may and often do have different consequences at different levels of system organization (Odum and Arding 1991). The general rule is that analyses at three levels of organization (the system of concern, its subsystems, and the next larger system) are the minimum required for a thorough understanding of a particular system. The West Virginia emergy analysis presented in this report varied from this standard because it used past analyses of the nation and did not include an examination of important subsystems within the state, *e.g.*, the coal industry; therefore, it is only the first step in a complete emergy analysis of the state.

2.1 Understanding the System

Effective models and analyses depend on the degree to which the investigators understand the system that they have chosen to analyze. For this reason, a thorough study of the system to be analyzed and its relationship to the next larger system, which determines long-term trends, is a prerequisite for successful analysis. Before performing emergy analyses of states or other systems, we recommend that investigators review existing studies containing current and historic information on the state with a view toward characterizing it as an environmental system. Environmental systems include the economic and social infrastructure and activities of humanity as well as the storages, flows and processes of ecosystems. In the method presented here and illustrated in the Results section, the knowledge gained through this review is captured in the narrative history of the state. The narrative history is a vehicle for understanding how renewable and nonrenewable resources have shaped the current economy in the state. Setting down the history of the state helps trace causal pathways from the past to the present and establishes the historical context of changing relationships between the state and the nation. The knowledge gained through this review serves as a basis for creating a detailed energy systems diagram of the state as discussed below.

2.2 Overview of Emergy Analysis Methods

There are five main steps required to complete an emergy evaluation. First, a detailed systems diagram is completed. The second step is to translate this knowledge into an aggregated diagram of the system addressing specific questions. Third, descriptions of the pathways in the aggregated diagram are transferred to emergy analysis tables where the calculations needed to quantitatively evaluate these pathways are compiled. The fourth step in the method is to gather the raw data needed to complete the emergy analysis tables along with the conversion factors (energy contents, transformities, etc.) needed to change the raw data into emergy units. Finally, after the raw data has been converted into emergy units, indices are calculated from subsets of the data. These five steps are discussed in more detail in the following sections.

2.2.1 *Diagramming and Models*

First, a detailed energy system diagram is constructed representing all interactions between human and natural components of the system that have been identified as relevant (Fig. 1, p. 2-14). The Energy Systems Language symbols and their intrinsic mathematics (see Appendix A, Fig A1 and Odum 1994) are used to develop models of ecological and socioeconomic interactions and components representative of the functions and structures within the system. In an energy systems diagram, structure encompasses the system components and their arrangement, and function includes pathways of energy flow and their interaction in processes. Components can be both physical entities and properties such as information or aesthetics that are usually considered as intangible, but require small energies for their storage and operation and thus can be documented. The pathways and interactions can be both physical flows such as electricity or raw materials as well as control mechanisms, *e.g.*, logic programs controlling animal migrations or management decisions.

It is important to include all known connections between system components in the draft diagram to insure completeness of the evaluation. A diagram like this is a useful tool for defining data needs. Once the exercise of defining all known interactions that affect the system components is completed, there is usually enough information to construct working hypotheses about the mathematical expressions that govern these processes. This in turn points to the appropriate factors that need to be measured when field work is required.

Variables in the detailed model are then aggregated, according to similarity of function, into variables considered important in controlling system behavior that is relevant to specific research or management questions. Preliminary evaluations of the emergy in system storages and flows helps in determining the dominant components and processes of the system that should be included in the aggregate diagram. Aggregating does not mean removing any component from the system. It refers to combining components and using either averaged data or data from the dominant entity to evaluate the component or process. For example, data on a biological component can be weighted for population percentages. The goal of aggregation is to obtain the simplest possible system that still allows the original research or management question to be answered.

Committing concepts of the energy connections and storages within an ecosystem to paper invites review of the completeness and accuracy of the conceptual thinking. It is not necessary to include all known details in every diagram. In the emergy accounting procedure presented in this document, the pathways of primary interest are those crossing the boundaries, both as inputs and as outputs. At this scale, the focus is on the external flows supporting the environmental system. The only internal interactions of interest are the extractions of natural resource storages for economic use, *e.g.*, coal or minerals. Other internal paths are drawn, but much of the detail concerning the workings of each component can be omitted.

2.2.1.1 *The Energy Systems Language*

The tools and methods for constructing an energy systems diagram are discussed extensively in Ecological and General Systems (Odum, 1994). The Energy Systems Language is a visual mathematics because each symbol is mathematically defined. A network of these symbols translates directly into a set of simultaneous 1st order differential equations. Energy Systems diagrams represent both kinetics and energetics in a single diagram and they demonstrate and obey the 1st and 2nd laws of thermodynamics in their structure. The commonly used symbols and conventions of the language are briefly described below to assist the reader in understanding the energy systems diagrams used in this document (Figure A1).

System boundary. A rectangular box represents the system boundaries selected. This is an arbitrary decision and boundaries are often chosen to address an issue or question being evaluated. The boundary determines the spatial and temporal scale of the analysis.

Forcing functions. Any input that crosses the boundary is an energy source for the system, including pure energy flows, materials, information such as the genes of living organisms and human services, as well as inputs that are destructive. External inputs are represented with a circular symbol and are arranged around the outside border from left to right in order of increasing transformity with sunlight on the left and information and human services on the right.

Pathway lines. Flows are represented by a line and include energy, materials, and information. Money is shown with dashed lines and always flows in the opposite direction to the material or energy flow with which it is coupled. Lines without arrowheads flow in proportion to the difference between two forces and represent a reversible flow due to the concentration gradients.

Outflows. Any outflow that still has available energy, *e.g.*, materials more concentrated than the environment or usable information, is shown as a pathway exiting from any of the three upper system borders, but not from the lower border. Degraded or dispersed energy, with insufficient ability to do work in the system, is shown with gray lines leaving at the bottom of the diagram through a single arrow going to the heat sink.

Adding pathways. Pathways add their flows when they join and when they enter the same storage. Every flow in or out of a storage must be of the same type and is measured in the same units.

State variables. Storages of material, energy and information are shown as tanks (Fig. A1) within each system compartment. Changes in the system can be recorded as fluctuating accumulations within each tank. In system diagrams using group symbols, *e.g.*, producers and consumers, the actual simulation details, such as tanks and complex interactions may not be presented. However, a state variable is always implied for every storage within the diagram whether it is shown or not.

Intersection/interaction. Two or more flows that are different, but required for a process, are drawn entering an interaction symbol. The flows to an intersection are connected from left to right in order of their transformity, the lowest quality one connecting to the notched left margin and the higher quality flows connecting to the top of the interaction symbol. Photosynthesis is an example of a multiplicative interaction in which light, plant biomass, and nutrients are the inputs required to produce organic matter. However, any mathematical relationship can be used to define an interaction and an appropriate symbol or notation made on the interaction symbol. A flow of one entity cannot go from its tank to a tank with a different entity without passing through some interaction, *e.g.*, sunlight cannot flow into a tank of phytoplankton carbon without first interacting with nutrients, phytoplankton biomass and other inputs, to produce a flow of carbon in gross primary production. If hierarchical symbols are being used, *e.g.*, the producer or consumer or a rectangular box for a subsystem (Figure A1), disparate flows can enter the symbol without showing the interactions. However, the interactions are implied and are shown explicitly when the hierarchical symbol is completely specified (Odum and Odum 2000).

Counter- clockwise feedbacks. High-quality outputs from consumers, such as information, controls, and scarce materials, are fed back from right to left in the diagram. Feedback from right to left also represents recycle or a loss of concentration, because of divergence, with the service usually being spread out to a larger area. Feedback control or recycle paths go from right to left over the top of all other components and pathways.

Sensor. If the quantity of a component in some way affects a flow without using up the component, a small box (sensor) is placed at the top of the storage tank and information on the stored quantity is drawn from this point for use by another symbol, *e.g.* an interaction or logic program. For example, the amount of money a region has might influence the number of invitations the community receives to participate in an event, but money itself was not sent to get these invitations.

Material balances. Since all inflowing materials accumulate in system storages or flow out, each inflowing material such as water or money needs to have a budget determined.

2.2.1.2 *Simulation Models*

Microcomputer simulation is a standard tool of emergy analysis that is not used in this report, but should be mentioned in the interest of completeness. Simulation models are often helpful in considering alternatives, investigating dynamic properties, and making predictions. They act as a controlled experiment and allow the investigator to adjust one

Table 1. Tabular Format for an Emergy Evaluation

Col. 1	Column 2	Col. 3	Column 4	Column 5	Column 6
Note	Item	Data	Solar Emergy/Unit	Solar Emergy	Em$
		J, g, $	sej/J, sej/g, sej/$	sej, sej/y	Em$/y

variable at a time and note the resulting changes to the system. In creating a simulation model, an evaluated diagram showing the initial conditions for all state variables and pathway flows is made. Storages and flows are determined from literature or field measurements of biomass, production rates, etc. The simulation model is translated into a set of simultaneous first order differential equations containing the mathematical functions governing rates and interactions that result in changes in the state variables under a given set of forcing functions. These differential equations are written as difference equations in a programming language and solved on the computer to predict the changes in each state variable as a function of time or space. More detail on the use of models and simulation in energy systems analysis can be found in Odum and Odum (2000).

2.2.2 Emergy Tables

The common format used to set up emergy tables is illustrated above. Each emergy evaluation table has six columns as shown in Table 1:

The columns are defined as follows: Column 1: Note. The line number for the item evaluated is listed. Each line number corresponds to a footnote in a table where raw data sources are cited and calculations shown. The footnotes referenced on tables in this paper maybe found in the appendices. Column 2: Item. The name of the item is listed. Column 3: Data. For each line item the raw data is given in joules, grams, dollars or some other appropriate unit. The source, derivation and characteristics of this data should be shown in the footnotes. Column 4: Solar Emergy per Unit. For many items the solar emergy per unit (transformity where the unit is energy) has already been calculated in previous studies. If it has not, the solar emjoules per unit can be calculated using one of the methods listed in Odum (1996). Transformities and other emergy per unit ratios used in this report are documented in Appendix B. Column 5: Emergy. The solar emergy is given here. It is the product of columns three and four. It can be an emergy flow (sej y^{-1}) or emergy storage (sej). Column 6: Emdollars. This number is obtained by dividing the emergy in column 5 by the emergy/dollar ratio for the economy in the selected year. The emergy analysis tables provide a template for the calculation of the emergy values for energy sources and flows. In the emergy tables, raw data on the mass of flows and storage reserves are converted to energy and then to emergy units and emdollars to aid in comparisons and public policy inferences. Emergy tables are used to create the accounts for the emergy income statement and emergy balance sheet.

2.2.3 *Data Sources and Model Evaluation*

In general, government sources are the first choice for environmental and economic data acquisition. For the emergy analysis of a state, U.S. government sources are preferred. A list of sources for the information used in this study is provided in the Data Sources section of this report. Government sources are most likely to provide detailed descriptions of assumptions and methods, and they often provide a quantitative estimate of error. Recorded data specific to the system both in time and space are preferred. However, data are rarely collected in a manner that can be directly inserted into an emergy evaluation table. For example, international trade exchanges are meticulously recorded by several federal agencies, but domestic trade is evaluated only through surveys conducted five years apart. Furthermore, a great deal of economic information is recorded in terms of currency exchange, but because unit prices vary substantially, it is difficult to estimate the actual resource or environmental use involved. In these cases, broader based assumptions and accepted models, many of them models employed by economists, are used to convert the recorded data into estimates for a particular area or system.

The information needed for the emergy income statement is most often reported as annual flows of dollars and/or mass. Often mass can be easily converted to energy because the energy content of many objects has been widely tabulated *(1)*. (Numbers in italics follow data sources mentioned in the text and refer to entries in Section 6, Data Sources). The energy contents of many materials evaluated in this study are given in Appendix C. The *specific emergy* or the emergy per unit mass has also been calculated for many items and can be used to convert mass flows to emergy when it is convenient (see Appendix B). Dollar flows can be converted to the average emergy in the human services associated with the good or service purchased by multiplying the dollar amount by the appropriate emergy to dollar ratio (Odum 1996). However, the dollar value of something does not give an accurate estimate of its emergy except when the work of humans accounts for all but a small part of the emergy required to make the item.

2.2.4 *Transformities*

The energy content of many items has been tabulated; however, the information available on the solar transformities of those items is often more limited. Thus, the availability of data on solar transformities often determines the ease with which emergy accounting studies can be performed. Many solar transformities have been calculated (see Appendix C in Odum, 1996 and Appendix B below), but most studies require the calculation of new transformities or the updating of old transformities, when the average or general value for the transformity of an item is not appropriate to answer the management or research question. Although several methods for calculating transformities exist (Odum 1996), transformity calculations are commonly based on an analysis of the production process for a particular item. Global production processes are used to determine the transformity of planetary products like the wind, rain and waves (Odum 1996, Odum 2000). The relevant production processes of environmental and economic subsystems are analyzed to determine the transformities for particular economic or ecological products and services. For example, the inputs to agricultural production processes for different crops in Florida were evaluated to obtain transformities for soybeans, grain corn, potatoes, etc. (Brandt-Williams 2001). All energy inputs required for the production of an item are documented and converted to solar joules (by multiplying each energy input by the appropriate transformity). Emergy inputs to the process are summed and divided by the available energy in the product to obtain the transformity of that item in sej/J.

A distribution of values can be obtained for the transformity of any item by the analysis of many production processes. The thermodynamic limits on the efficiency of all production processes lead to the hypothesis that there will be a minimum attainable transformity, which results when the production process is operating at maximum power. This minimum transformity may be a constant for a given product or service that indicates its location in the hierarchy of all natural processes. In practice, when a general value for a transformity is to be determined, a well-adapted (fast and efficient) production process is evaluated on the scale and in the setting under which the product is commonly formed. For example, rain and wind are products of the global atmospheric heat engine and thus their transformities are determined through an analysis of the global hydrologic cycle. In any emergy analysis, it is important to consider whether the energy and material inputs to a production process can be considered to be of average transformity for that item. If so the general value for the transformity for these items can be used. For example, electricity can be generated by many processes (using wood, water, coal, gas, tide, solar voltaics, etc) each with a different transformity (Odum 1996). An average value of 1.7 E5 sej/J was determined by Odum (1996), which is consistent with the transformity of electricity generated from coal-fired power plants such as those found in West Virginia. The use of a general transformity for an item is appropriate when (1) the item is representative of the mix of production processes that determine the mean, (2) the general value reflects the specific input, and (3) the transformity of the particular item is unknown. It would not be reasonable to use the general transformity for an item when the system or process under evaluation is known to be dependent on an inflow of higher or lower transformity energy.

Transformities are always measured relative to a planetary solar emergy baseline and care should be taken to ensure that the transformities used in any particular analysis are all expressed relative to the same baseline. However, all the past baselines can be easily related through multiplication by an appropriate factor and the results of an emergy analysis do not change by shifting the baseline (Odum et. al, 2000). The baseline used in this study is from Campbell (1998, 2000a) who calculated a revised solar transformity for tidal energy that resulted in a correction to the planetary baseline in Odum (1996) giving a new value of 9.26 E+24 solar emjoules joules per year. The transformities used in this report have either been calculated using the 9.26 baseline or multiplied by the appropriate factor to express them relative to this baseline. These factors are provided in Appendix B, Table B1.1, where transformities are also given relative to the 15.83 E+24 sej/y baseline promulgated in Odum et al. (2000).

2.2.5 *Flow Summary and the Calculation of Indices*

The final step in creation and analysis of emergy accounts for a system is to combine the information from the income statement into summary variables that are used in the calculation of emergy indices. These summary variables are shown on the aggregate diagram (Fig. 2, p. 3-12) discussed above and provide a macroscopic overview of emergy and dollar flows for the system. Other analysis methods and tools are used in Emergy Analysis (Odum 1996, Odum 1994) but these are not discussed here. Using the emergy analysis tables and the aggregated figures, emergy indices are calculated to compare systems, predict trends, and to suggest alternatives that deliver more emergy, reduce stress on the environment, are more efficient or more equitable.

2.3 Creating the Emergy Income Statement

The income statement can include the following tabular accounts: (1) the renewable resources received and used within the system and the production based primarily on the use of those resources, (2) production and consumption of nonrenewable resources within the system, (3) imports into the system, and (4) exports from the system.

2.3.1 *Evaluating Renewable Resources*

Renewable resources are replenished on a regular basis as a result of the use of planetary emergy inflows in solar radiation, the deep heat of the earth and gravitational attraction of the sun and moon. These primary planetary emergy inflows and the continuously generated co-products of their interactions in the geobiosphere comprise the renewable resources of the earth. In general, all renewable resources known to be important inputs to a system are evaluated and the emergy contributed to the system by each is determined. While all renewable energies known to be important are calculated and included in the table, not all of them are included in the emergy base for a system. If all the co-products of a single interconnected planetary system are counted, some of the emergy inflow will be counted twice; therefore, only the largest of any set of co-products is counted in the emergy base for a given area of the earth.

Rain carries two kinds of energy, the chemical potential energy that rainwater has by virtue of its purity relative to seawater and the geopotential energy of the rain at the elevation at which it falls. Renewable energy also enters a state or other system through cross border flows of energy and materials in rivers. Renewable energy inflows to the system can be determined at two points, (1) the point of entry and (2) the point of use. The first of these two flow measurements gives the emergy received by the system and the second gives the emergy absorbed or used in the system. For example, the incident solar radiation is received by the system and the incident solar radiation minus the surface albedo is absorbed. The geopotential energy of rain on land at the elevation it falls is the geopotential energy received by the system, whereas, the geopotential energy of the runoff relative to the elevation at which it leaves the state is used on the landscape to create landforms. The chemical potential energy of the rain that falls on the land is received, but the water transpired is actually used by the vegetation to create structures on the landscape. In some cases almost all the emergy received by the system is absorbed, *e.g.*, almost all tidal energy received is dissipated in estuaries and on the continental shelf.

An economy develops over many years in response to the environmental energies available to support human activities in the system; therefore, a long-term average of environmental variables, *i.e.*, 10 to 50 years depending on the available data, is used to calculate the average energy supplied to the system from renewable sources. Long-term averages for environmental data smooth temporal variations in the inputs of renewable energy, which might otherwise lead to high variability in the emergy indices based on year to year variability of renewable inflows. Environmental data should be collected with comparable technologies. Sometimes, with long environmental data sets, the technology used to obtain the data will have changed during the period of record. In this case, we try to use only the data recorded using the most recent instruments, which are comparable. Representative averages in space and time are also important to characterize inputs accurately. Where there are substantial differences in environmental inputs in different regions of a state, the differences should be prorated by area to insure that the most accurate estimate of the energy input to the state is obtained for any particular variable. For example, mountainous areas have a different climate than coastal areas. More specific methods for determining the emergy of renewable resources are provided in Appendix C.

2.3.2 *Evaluating Nonrenewable Resources*

Nonrenewable resources are raw materials that have been built over a long time by environmental processes, but that are being used by human activities at a rate much faster than they can be renewed. Coal mining or groundwater withdrawals in excess of the recharge rate are examples of nonrenewable resources. An emergy evaluation does not determine the contribution of a nonrenewable resource by the price paid for the raw material – a ton of coal for instance – because this is not the value of the coal itself. It is the price someone is willing to pay for the labor and machinery required to mine the coal. When evaluating coal as an emergy input, it is important to evaluate or take into account the energy required to make the coal. The solar emergy required to make a joule of coal is its solar transformity in sej/J. A material flow is multiplied by its specific emergy (sej/g) or converted to energy and then multiplied by its transformity to obtain an emergy flow. All storages in the system that are being used faster than they are being replaced contribute to the non-renewable emergy supporting the system. This includes storages that can be used renewably, *e.g.*, soil, ground water, timber.

2.3.3 *Evaluating Exports and Imports*

Emergy is imported and exported in three forms: (1) emergy in services separate from any material flows (consulting, data analysis, financial services, etc.), (2) emergy in materials entering and leaving the state, and (3) emergy in the human service associated with the material inflows and outflows (collecting, refining, manufacturing, distributing, shipping, and handling). The data sources and methods used to evaluate imports and exports will vary depending on the system. The following methods are specific for the evaluation of imports and exports to and from a state in the United States.

Most of the data on the shipment of commodities between states is collected in terms of both the dollar value and tonnage shipped. Both kinds of data are needed to make estimates of emergy movements because goods have energy and emergy value associated with their creation and concentration in nature that is separate from the contributions of human service that are measured in the economic value of the good. Generally, the value, or the money paid for a material at the point of use reflects the service associated with that commodity. This dollar value can be multiplied by the national emergy to dollar ratio for the year of analysis to estimate the emergy of the human services accompanying the flow of imported goods. The fluxes of energy or mass in each material flow can be multiplied by the appropriate emergy per unit (excluding services) and the results summed to determine the total emergy in the import and export of the material in goods.

Determining the emergy in goods and services imported to and exported from a state is a difficult problem because data on the exchange of goods and services is collected at different points, by different government agencies, using different methods of aggregation and estimation. Furthermore, while imports and exports are tracked at the national level using shipping labels that have explicit information, the domestic distribution of goods is determined by the statistical analysis of survey data and other economic modeling methods. Domestic energy shipments are the only commodities tracked on the basis of a nearly complete accounting of actual state-to-state movements of the commodity. Petroleum is an exception to this level of detailed accounting because its movements are only tracked among regions.

The detailed export profile estimates and the overall information on state-to-state movements of goods in the Commodity Flow Survey (CFS) *(2)* were used to determine both the exports from and the imports to a state by product category. In addition, other sources were consulted to get a more complete accounting of goods crossing the state boundary and to check the CFS numbers wherever possible. All of these data are available on government websites (see Data Sources).

2.3.3.1 *Determining the Emergy in Materials*

Theoretically, determining the emergy in material inflows should be straightforward; however, the data reported are not complete. Although a total dollar and tonnage value are given for inbound and outbound shipments in the CFS for each state, some individual commodity classes are missing an estimate for dollar value, tonnage or both. This situation occurs most commonly because shipments are too variable to make the average a useful parameter or because a value, if given, would reveal information about an individual firm. A price per ton can be estimated from the data wherever the dollar value and tonnage are provided. Often both dollar value and tonnage for commodities are available for the total shipments out of a state. If the tonnage data was missing for a commodity in the shipments to a particular state, the dollar per ton value from the total shipments was used to estimate the unknown tonnage. Where flows are present but both tonnages and dollar values are unreported a tonnage-weighted export profile of commodities based on their respective fraction of total shipments was used to estimate the missing tonnage and to bring the total for all commodities exported to the total reported in the CFS (see Appendix D).

The Energy Information Administration (EIA) data on energy movements of coal and natural gas are estimated using multiple sources; and therefore, these data are considered to be more accurate and complete than the CFS data, which are estimated from the results of a survey. The EIA data are used to check and replace, if needed, the coal entries in the CFS. In addition, a category for natural gas data is added. Natural gas movements through existing pipelines can be determined as well as natural gas exports or imports from or to the state.

All materials that are prepared for shipment from a state are reported as exported in the CFS. However, some of these materials end up within the state of origin. The materials actually exported from a state are determined by subtracting the tonnage of shipments that begin and end in the state of origin from the total tonnage of shipments in each commodity class.

While the amount of goods imported into a state are not directly tracked in the CFS, the destination state for exports is reported, and consequently, the goods imported to a state can be determined by adding up the tonnage within each commodity class exported from the other 49 states to the state under analysis (West Virginia). If a state has a customs entry point, the U.S. Customs data on imports is added to the totals for each commodity class. The interstate shipment of goods tracked by the CFS includes all the goods shipped from a state regardless of origin, therefore international imports need only be included for states with ports of entry.

The 1997 Commodity Flow Survey reported commodities using a two-digit Standard Classification of Transported Goods (SCTG) code. This code is different from the Standard Industrial Classification (SIC) and the North American Industry Classification System (NAICS), both of which are used in U.S. economic data reports. Both import and export data are included in the CFS, but conversion is not necessary unless the state has a foreign customs entry point (West Virginia does not). Imports listed by NAICS categories were converted to SCTG categories using an approximate conversion scheme that we developed for the different industry classification codes (see Appendix D, Table D1.1).

The emergy in materials exported from or imported to a state is then determined by multiplying the mass or energy flow in each commodity class by the appropriate emergy per mass or transformity, respectively, based on an average of these ratios for the major material items moving in the class (Appendix B, Table B2.1). Outflows or inflows are then summed across all commodities to get the total emergy exported or imported.

Three key data sources for export/import calculations are the 1997 Commodity Flow Survey *(2)* the Department of Energy's Energy Information Administration *(3)* and import data from the US Customs Office and the Office of International Trade *(4)*. In addition, data for natural gas and coal shipments came from Department of Energy (DOE) documents *(5, 6)*. A step-by-step method for completing tables to calculate exports and imports is given in Appendix D.

2.3.3.2 *Determining the Emergy in Services*

Services can be tracked along with goods and the services associated with goods using total receipts for the different industry sectors along with sector employment. These numbers are recorded for both the United States as a whole and for each individual state using the same methods, but there is no distinction between goods and services that remain within the state and services that are transferred to other states. A variation of the economic base-nonbase method was used to estimate the emergy imported and exported in services. The information on the base-nonbase method used in this report can be found at the web address *(7)* given in Data Sources.

Economic base theory is usually employed to analyze the growth potential and stability of an economy in terms of its export industries *(7)*. In this method, economic sectors are designated as basic (exporting sectors that are largely dependent on areas external to the state or region for marketing their goods and services) or non-basic (sectors whose products and services are mainly used within the state or local region of analysis). Once the industry data has been gathered and the assumptions about sector behavior have been recorded, an estimation of exported and imported services can be made.

The underlying assumption behind the base-nonbase method of estimation is that the aggregate demand of the people in a nation will be satisfied by the total production of goods and services in all sectors of the national economy. Thus the ratio of workers in any sector to total employment for the nation indicates the level of economic production necessary to satisfy the average needs of the people. The number of workers in any given economic sector in a state as a fraction of the total workers in that state compared to a similar ratio for the nation is an indicator of the excess or deficit production capacity that may exist within that sector in the state's economy. This ratio is the location quotient (LQ) and it can be used to determine whether a given industry sector produces exports. If LQ is greater than one, at least some of the sector is basic (exporting). If it is equal to one, the sector production is assumed to just meet local demand and there is no excess to export. If the LQ is less than one, the local economic sector cannot satisfy the average demand and thus it is assumed that no net export will occur. Sectors with location quotients less than one are potential importers of goods and services in that sector. The formula to calculate the LQ for employment, S, in industry sector, i, within the economy of a state with total employment, S_t, referenced to employment in the same industry sector of the national economy, N_i, and total national employment, N_t, is given below.

$$LQ = \frac{S_i}{S_t} \bigg/ \frac{N_i}{N_t} \qquad (1)$$

The following equation was used to determine the number of basic jobs, B, in the export portion of an industry:

$$B = \left[\left(\frac{S_i}{N_i} \right) - \left(\frac{S_t}{N_t} \right) \right] \times N_i \qquad (2)$$

The number of basic sector workers, B, times the productivity per worker in the state industry gives an estimate of the dollar value of exported services. Multiplication of this number by the emergy to dollar ratio for the nation gives an estimate of the average emergy exported from a sector. If both goods and services are exported from the sector, the dollar value of the goods exported must be subtracted from total sector exports to estimate services. Alternatively for sectors that export both goods and services, the above method can be applied to more detailed data from sub-sectors that are almost entirely services and the export determined based on these sector divisions.

An estimate of the potential import of services to a region can be obtained in a similar manner. Under the assumptions given above, the deficit in employment in an industry sector should indicate the amount of service that would need to be imported for the residents of a region to enjoy the same level of service from these sectors experienced by an average person in the nation. To estimate imported services from the calculated potential, states above the average per capita income in the nation are assumed to be able to fill all their need for services, whereas states below this level were assumed to be able to fill only part of their needs. For example, West Virginia is a state shown to be impoverished by many social and economic indicators, *e.g.*, in 1997 West Virginia ranked 49th among the 50 states in per capita income *(8)*. Following the assumption given above, we assumed that West Virginians could purchase services in proportion to the ratio of West Virginia's 1997 per capita income to the 1997 national average per capita income. This number is only an estimate and the actual value of services entering the state is unknown. Assumptions governing the export and import of services from different industry sectors might be expected to vary somewhat based on the particular economic circumstances of individual states. In using this method, it is important to ascertain the facts about a given state's economy and to make supportable assumptions about service import-export relationships based on those facts. Steps in the method to calculate services are given in Appendix D.

2.4 Creating the Emergy Balance Sheet

The emergy balance sheet is a table containing the evaluation of the emergy stored in the assets of the system. The determination of some stored assets on the balance sheet of a state or region requires knowledge of the emergy input over the average turnover time of the storage. For example, to determine the emergy required for a forest of trees that are on average 40 years-old, the average annual energy used to support an area of forest (chemical potential energy of the water evapotranspired) would be multiplied by its transformity and then that number multiplied by 40 to determine the emergy required to develop the standing crop of trees comprising the forest. In evaluating an economic production process, start-up or capital costs are prorated over the average lifetime of the facility carrying out a production process. If the energy or mass of storage present in the system is known, this quantity can be multiplied by its transformity or specific emergy to obtain the emergy of the stored asset. For example, the estimated recoverable coal reserves in grams could be multiplied by the heat content in J/g to get energy and then by the transformity of coal (sej/J) to find the emergy of the stored asset. Complete methods of developing the emergy balance sheet including the documentation of environmental liabilities are under development (Campbell 2004).

2.5 Constructing the Emergy-Economic Overview

Information from the completed emergy income statement tables is combined to create a Table of summary flows, which provides the quantities needed for the calculation of emergy indices. These summary flows are also placed on the aggregated overview diagram of the system (Fig 2). The item name often is sufficient to identify a quantity, but where it is not, additional explanation is given in the Table notes along with how the quantity was derived. The evaluated energy systems diagram of the macroscopic economic and ecological features of the system (See Fig. 2) shows important classes of flows, the details of emergy and money movements across system boundaries, and a limited number of flows within the state. The inflows of renewable and purchased emergy and the outflows of emergy in products and services are summarized in an even simpler “3-arm diagram” (Fig. 3) that shows only the inputs to and outputs from the system.

2.5.1 *Summary Emergy and Dollar Flows*

The summary table includes information on all the important emergy and dollar flows for the system designated with a letter for each category of flow (see Table 9). Numerical subscripts after a letter symbol denote a particular flow of a given type. The renewable energy inflow to the system is designated with the letter “R”. The letter “N” indicates nonrenewable energy sources and any renewable sources that are being used faster than they are replaced, *e.g.*, soil, timber, groundwater. Flows shown using the letter “F” are fuels and minerals imported and/or used within the state. The gross economic product of the state (GSP) is designated with the letter “X”. The letter “G” designates imported goods excluding fuels and minerals. The dollars paid for all imports are shown with the letter I, and subdivisions of this sum are given by the subscripted letter. The dollars brought into the state as Federal transfer payments are listed with other dollar inflows (Table 6 and Figure 2). The letters “PI” designate the emergy flows in human service that are embodied in the dollars paid for imported goods and services. Exported products (goods + electricity) are represented with the letter “B”. The dollars paid for exports are shown with the letter “E” and the emergy that accompanies the human service embodied in these exports is shown as “PE”.

Money entering the state does not bring emergy into the state *per se*. However, when spent, money generates emergy flows. The emergy flows generated when tourist dollars are spent in the state are included as emergy exports in Tables 7 and 9. Campbell (1998) argued that tourists receive value from their recreational experience and that these experiences are virtual emergy flows that require unique emergy storages and flows to exist within the system for their creation. In this analysis the emergy purchased by the dollars tourists spend within the state is taken as a first order estimate of the emergy value of their recreational experience. These experiences are classified as exports, because they would not be possible without the unique recreational opportunities provided by the emergy stores and flows that are present in West Virginia.

One hypothesis is that Federal transfer payments may flow as a counter current to the overall emergy received by the nation from a state, where the emergy received by the nation exceeds that expected from the monetary exchange , *i.e.*, the monetary exchange balances but the emergy exchange does not. This relationship has not been proven, and federal outlays add emergy flows to the state when these monies are spent within the state, *i.e.*, at the state’s emergy to dollar ratio. In this latter view federal outlays would be imports and federal taxes exports because they represent a foregone opportunity to generate emergy flows within the state. Even though the former view of federal outlays may also be true we have chosen to view federal outlays as imports and federal taxes as exports in this paper.

2.5.2 *Determining the Renewable Emergy Base for a System*

The objective in determining the renewable emergy base for a given area of the earth is to evaluate the degree to which the earth’s renewable emergy sources have been concentrated in a given area. All significant inflows are identified and evaluated, but the items included in the renewable emergy base for the system are determined in a manner that avoids double counting inflows, *i.e.*, the base includes only the largest of the emergy sources entering the area that are co-products of the same generating process. For example, rain and wind are co-products of the work done by the planetary heat engine (the latitudinal gradient of temperature over the world oceans); therefore, only the largest would be counted toward the renewable emergy base for any given area. If a system includes land and sea areas, the renewable emergy base can be determined for each area and the two inputs summed to obtain the renewable emergy base for the entire area.

Planetary processes are considered to be one interconnected system for the purpose of determining the transformities of global products, thus the entire emergy input to the earth is necessary for the formation of all global co-products, regardless of the baseline. As a result the rules to minimize double counting in determining the natural emergy base for a given area of the earth will be the same for all baselines. The simple rule to avoid double counting when using the 15.83 or the 9.26 baseline to determine the renewable emergy base for a system is to only count the largest inflowing emergy of all the co-products of the planetary system (including tide) as the emergy base for any given area of the earth. Under this rule different areas in the same system may count different single emergies as the direct base, *e.g.*, tide for a state's area of coastal ocean and the chemical potential energy of rain for the land area of the coastal state can be added together to get the renewable emergy received by the entire area of the state. The same spatial resolution for determining the emergy inflows must be used to insure that bases are comparable. Where emergy inflows are concentrated in space, higher resolution of the inputs will result in a greater emergy base for the system. For example, at a resolution of 100 m, the zone of breaking waves would be resolved for a coastal system and the wave emergy absorbed might be added to the emergy base for the system after adjustment of the area of the other inputs, and if it is the largest input received over the area of the 100 m wide coastal strip. This dependence on spatial resolution requires that the emergy analyst consider differences in the emergy signature across the landscape where they exist, thus areas of different biogeographic characteristics are considered separately and the largest emergy inflows to each are combined to represent the total system (Campbell 2000a).

2.5.2.1 *Renewable emergy received*

For any area, use the largest of the energy sources supplied by the planetary processes (rain, wind, waves, earth cycle, tides. etc.) at the point that they enter the system and sum over the entire area of the system to determine the renewable emergy received. For rivers that cross into a state or flow along its borders, the emergy received at the point the river enters the state is included in the emergy base. If the river flows along the border between two states, ½ of the emergy received is given to each state.

2.5.2.2 *Renewable emergy absorbed*

Both the emergy in chemical potential energy (evapotranspiration) and the geopotential energy (runoff) of water doing work in the system are counted, because the water used in these two processes is distinct. These two forms of energy carried by water interact across the elevation gradient from mountains to the sea to maximize empower on the landscape (Romitelli 1997). All tidal energy received is assumed to be used within the estuarine and continental shelf area and all wave energy is assumed to be used when waves break on the shore. The chemical potential and the geopotential energy of rivers used in the state is found by determining the chemical and geopotential energy at the point where the river leaves the state and subtracting this from the respective potentials at the point of entry. For example, a river enters the state 500 m above sea level and leaves at an elevation of 250 m, the difference in geopotential energy of the annual water flows at these two points is the geopotential energy used within the state.

2.6 Emergy Indices

Emergy indices are often meaningful to characterize the condition of a region and determine the relationship between the region and the larger system. The emergy indices are calculated by performing various mathematical operations with the quantities given in the Flow Summary Table. The emergy indices used in this study are identified and explained below.

2.6.1 *The Emergy/Money Ratio*

The ratio of emergy to money is a useful index because it connects aggregate economic activity to the emergy flows that support it. An emergy to money ratio is obtained by dividing the total emergy use of a state or country by its gross economic product. The result is the average amount of emergy that is purchased by spending a dollar in a certain place (sej/$). In other words the emergy/dollar ratio tells us the purchasing power of a dollar in terms of the real wealth (emergy) that it can buy. Money is used to purchase products such as food, fuels, clothing, housing, electricity, information, etc. according to their market price. Each of these products also has an emergy value. In addition, many products of nature contribute to these economic products but are not traded in the market and thus have no market value. Dividing the emergy of a product or service by the emergy to dollar ratio for its system gives the emdollar value of the item. The emdollar value of a product or service represents the portion of the total purchasing power in the system that is due to a particular product or service from the economy or from nature. The emergy to dollar ratio has another useful property. Because dollars are only paid to people for their services, the emergy to dollar ratio for a system can be used as an estimate of the average value of human services in that system. Thus, multiplying a dollar value of a product or service by the emergy to dollar ratio gives, on average, the emergy equivalent of human service embodied in that item.

2.6.2 *The Emergy Exchange Ratio*

The emergy exchange ratio (EER) is the ratio of emergy received to the emergy given in any economic transaction, *i.e.*, a trade or sale. The trading partner that receives more emergy will receive greater real wealth, and therefore, greater economic stimulation due to the trade. Indices of equity in exchange between states and nations are determined by comparing the emergy in imports and exports. The difference between imports and exports indicates whether the state or region is a support area for other regions and/or the larger system. The ratio of exports to imports indicates the degree to which a system contributes emergy to or receives it from a trading partner or its larger system. When applied to individual products, the EER gives the emergy advantage to the buyer by determining the emergy of the exported product relative to the emergy that could be purchased with the buying power of the money received in exchange.

2.6.3 *The Investment Ratio*

The investment ratio is the ratio of the solar emergy purchased from outside the system to the solar emergy supplied by the renewable and non-renewable energy sources from within the system. It shows the matching of economic investment to the indigenous resources of a state or region. Lower values of this ratio indicate that the indigenous environmental resources are supplying relatively more emergy per unit of economic activity, and therefore, environmental resources may be available and capable of stimulating investment and additional economic use. The ratio of purchased to free emergy is a variation of the investment ratio, which compares purchased emergy with the free contributions of renewable emergy. Empower density or the emergy flow per unit area is a related measure that indicates the spatial concentration of economic activity or the intensity of development in a state or nation.

2.6.4 *The Environmental Loading Ratio*

The environmental loading ratio (Odum 1996, Brown and Ulgiati 2001) is the ratio of the emergy used from nonrenewable sources (including renewable sources being used in a nonrenewable manner) and the emergy imported in goods and services to the renewable emergy used. It indicates the expected intensity of impacts to the renewable emergy base of the system and the probability that the system will have incurred significant environmental liabilities on the balance sheet.

2.6.5 *Indices of Self-Sufficiency And Dependence*

The emergy used from home sources as a fraction of total emergy use is a measure of the relative self-sufficiency of a state or region. Conversely, the fraction of total emergy use purchased from outside shows the dependence of a state or region on the larger economy of which it is a part. The fraction of use that enters as imported services indicates the relative dependence of the state on the service economy of the nation.

2.6.6 *Indices of Sustainable Use*

The fraction of use that is free and the fraction of use that is renewable are indicators of what is sustainable in the long run. If the difference between these two indicators is large, it shows that the long-term capacity of the renewable emergy sources to support life is being degraded. Truly sustainable use is based on renewable resources alone used in a renewable manner. A quick estimate of the renewable carrying capacity of a state at the current standard of living is obtained by multiplying the fraction of use that is renewable by the present population of the state. Sometimes the developed carrying capacity at the current standard of living is also estimated by multiplying the above number by 8, an average ratio of purchased to renewable emergy in developed countries from past studies (Odum 1996).

2.6.7 *Indices of Quality of Life*

The annual emergy flow per person is hypothesized to be an index of the overall standard of living that includes environmental and economic contributions to the quality of life. This assumes that the people living in the system actually benefit from the energy used there. Quality of life is also indicated by the emergy in electricity use as a fraction of total use. This ratio is a measure of the relative importance of the higher transformity activities of people, and therefore, it should be correlated with the contributions of technology to higher standards of living.

2.7 Energy and Emergy Signatures

Energy and emergy signatures of a system show the magnitude of environmental and economic inflows and outflows of a system on a synoptic plot that is useful in characterizing and classifying systems. The energy signature is a bar graph of energy flows with the magnitude and direction of the flow (in or out of the system) in joules per year shown on the ordinate and the type of energy flow identified on the abscissa. A bar graph of the same flows converted to empower (sej/y) is the emergy signature of the system. Conversion of energy flows to empower shows the relative contributions of the various energy inputs in terms of equivalent ability to do work. If functionally distinct areas have different emergy signatures (Campbell 2000b) and similar areas exhibit similarities in their emergy signature, the emergy signature may be useful in classifying different environmental systems based on differences in their inputs (Odum et al., 1977).

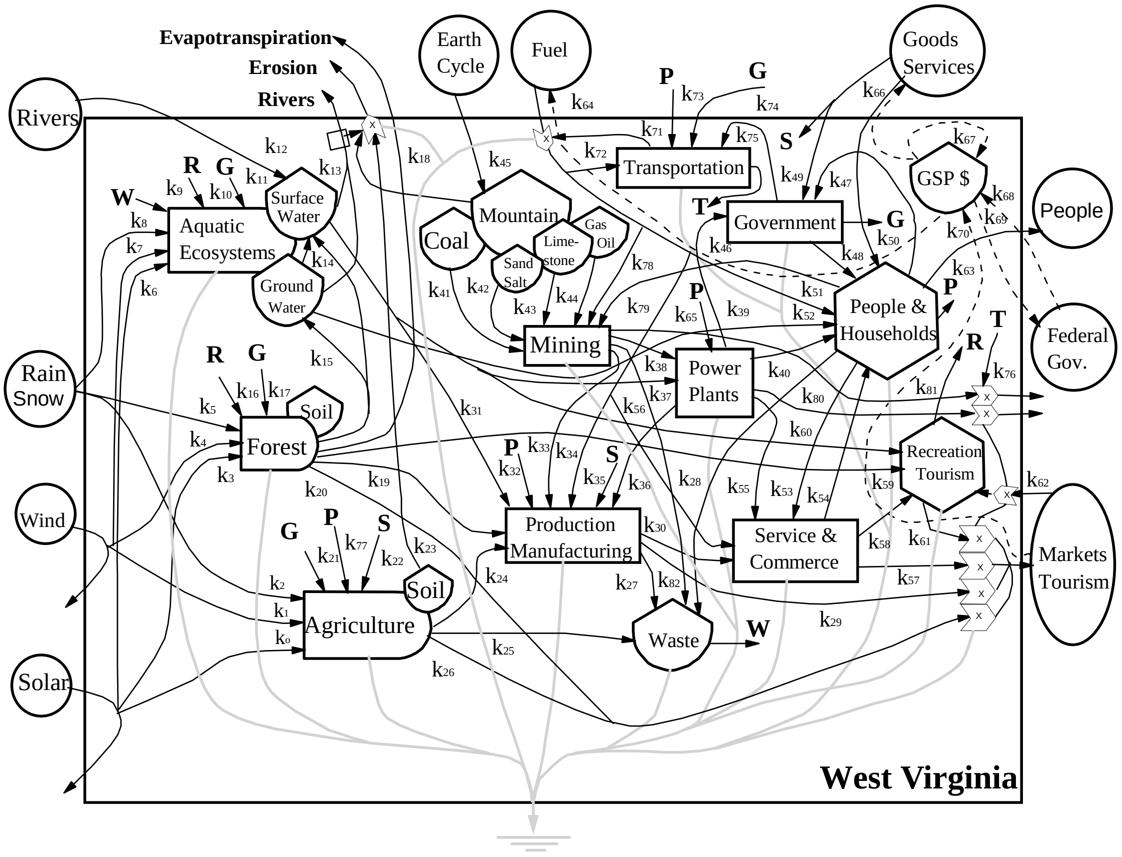

Figure 1. A detailed energy systems model of the State of West Virginia (see Tables 2&3 and Appendix A). The large capital letters show connections between sectors where a line would be cumbersome.

Table 2. Definition of pathway flows for the systems model of West Virginia's environment and economy shown in Figure 1.

Pathway	Definition of Flow
k_0	Solar Radiation absorbed by farmland
k_1	Wind energy absorbed by farmland
k_2	Rain fall on farmland
k_3	Solar radiation absorbed by forestland
k_4	Wind energy absorbed by forestland
k_5	Rain fall on forestland
k_6	Solar radiation absorbed by surface water
k_7	Wind energy absorbed by surface water
k_8	Rain fall on surface water
k_9	Waste discharge into rivers and streams
k_{10}	Environmental effects of recreational water activities
k_{11}	Government improvements to rivers
k_{12}	River inflow from outside the state
k_{13}	River water flowing out of the state
k_{14}	Ground water base flow to rivers
k_{15}	Fresh water recharge by forests
k_{16}	Environmental effects of recreation on the forest
k_{17}	Government management actions to improve forests
k_{18}	Evapotransporation from forests
k_{19}	Forest products used by industry
k_{20}	Forest products exported directly
k_{21}	Government inputs to agriculture
k_{22}	Pesticide, fertilizer, and other inputs used in agriculture
k_{23}	Soil losses due to erosion
k_{24}	Agricultural products used by industry
k_{25}	Waste produced by agriculture
k_{26}	Agricultural products exported directly
k_{27}	Waste produced in manufacturing
k_{28}	Waste produced by people and households
k_{29}	Products exported from the state
k_{30}	Manufactured products sold in the state
k_{31}	Water used by industry
k_{32}	Labor used by industry
k_{33}	Mined products used by industry
k_{34}	Imported fuels used by industry
k_{35}	Goods and services used by industry
k_{36}	Electric power used by industry
k_{37}	Water used in power plants
k_{38}	Mined products used in power plants.
k_{39}	Electrical power used by government
k_{40}	Electricity used by people and households
k_{41}	Coal mined

Table 2. Definition of pathway flows for the systems model of West Virginia's environment and economy shown in Figure 1. (continued)

Pathway	Definition of Flow
k_{42}	Sand and salt mined
k_{43}	Limestone mined
k_{44}	Gas and oil mined
k_{45}	Earth cycle energy driving earth uplift
k_{46}	Electrical power used by the state government
k_{47}	Labor used by government
k_{48}	State and local government projects to benefit people
k_{49}	Goods and services from outside used by government
k_{50}	Imported goods and services purchased by people
k_{51}	Fuel used by people and households
k_{52}	Fresh water used by people and households
k_{53}	Labor used in the commerce and service industry
k_{54}	Local goods and services used by people of West Virginia
k_{55}	Electricity used in the commerce and service industry
k_{56}	Fuel used in the commerce and service industry
k_{57}	Commerce and service industries exports
k_{58}	Local goods and services used to support recreation
k_{59}	West Virginia forest supporting recreation
k_{60}	Fresh waters supporting recreation
k_{61}	Recreated tourists leaving the state
k_{62}	Tourists and seasonal residents entering the state
k_{63}	Net migration of people
k_{64}	Money spent on imported fuel
k_{65}	Labor used in the electric power industry
k_{66}	Money spent on imported goods and services
k_{67}	Money circulating in the state GSP
k_{68}	Federal subsidies to the state
k_{69}	Federal taxes paid by the state
k_{70}	Money acquired from exports and tourism
k_{71}	Transportation needed to move fuels into the state
k_{72}	Fuel needed to run and maintain transportation systems
k_{73}	Labor needed to run transportation system
k_{74}	Goods and Services used by transportation systems
k_{75}	Government contributions to transportation
k_{76}	Transportation systems used to export goods and services
k_{77}	Labor used in agriculture
k_{78}	Imported fuel used by the mining sector
k_{79}	Labor used in mining industries
k_{80}	Electric power exported
k_{81}	Coal exported
k_{82}	Wastes produced by the mining sector

Table 3. Definitions of the components for the systems model of West Virginia's environment and economy shown in Figure 1.

Component	Definition
Aquatic Ecosystems	All bodies of water that support an ecosystem in West Virginia, specifically the rivers and lakes
Surface Water	All rivers and lakes in West Virginia
Ground Water	The quantity of water held in aquifers in the state
Forests	All forest land both managed and unmanaged, including all hard and soft wood areas
Soil	The storage of topsoil in forests and farms
Agriculture	All crop, pasture and orchard land
Mountains	Mountain areas of the state
Coal	The storage of coal within the mountains
Sand and Salt	The storage of sand and salt within the state
Limestone	The storage of limestone in West Virginia
Gas and Oil	The storage of gas and oil
Mining, M	All mining industries including coal, sand, salt, limestone, gas, and oil
Production and Manufacturing	All manufactures of durable and non-durable goods including chemicals, pharmaceuticals, plastics, fabricated and primary metals, and glass, stone and clay products. Also includes fish production, farming, forest, and mining industries
Transportation, T	All elements of transportation, including movement by truck, train, and river
Power Plants	All fossil fuel, nuclear, and hydroelectric plants generating electricity in West Virginia
Government, G	State and local government
Service and Commerce	Wholesale and retail trade, hotels, restaurants, banking, real estate, insurance and construction companies, repair shops; the transportation industry, communication and utilities; health, legal, social, personal, and repair services; waste treatment, hospitals, schools and other government services
People and Households, P	The population of West Virginia and their assets (households)
Recreation and Tourism, R	All cultural and recreational activities in the state, including festivals, kayaking, rafting, hiking, camping, and historical sites
Waste, W	Waste products created by people, industry, and agriculture
GSP	Gross State Product

Section 3

Case Study - An Emergy Evaluation of West Virginia

An emergy analysis of the State of West Virginia is given in this section of the report to demonstrate the emergy accounting methodology. The application of emergy analysis methods in this case study shows how each of the techniques given in the methods section is performed. The calculations and assumptions used in each part of the analysis are documented and the sources of the information are given in the Appendices. This section is written as a stand alone report that can be used by scientists and managers who are interested in the results and conclusions of the case study, “An Emergy Evaluation of West Virginia”.

3.1 Introduction

The economic productivity and well-being of West Virginians are dependent on the health and vitality of their environment as well as the wealth of their stored mineral resources. However, the environmental contributions to West Virginia’s economy cannot adequately be evaluated by market values alone. There is an inverse relationship between the contribution a resource makes to the economy and its price (Odum 1996). For example, when timber is abundant, prices are lowest but the contribution of timber to that society is greatest because it is used for many purposes. On the other hand, after extreme logging, timber becomes scarce and the cost increases; timber contributions to the economy are lower because it is no longer commonly used (Odum, 1996). Economic studies evaluate wealth by what people are willing to pay for a commodity, but because money is not paid to the environment for its work, market values do not effectively assess environmental contributions to value (Odum, 1996). Emergy accounts include comparable estimates of the environmental, social and economic costs and benefits of alternative actions. Therefore, the creation and analysis of such accounts is needed to ensure that managers have all the information that they need to make decisions in the best interest of society.

At present, West Virginia is faced with the conflicting needs of its people and the nation. There is a national energy policy initiative for the United States to reduce its dependence on foreign sources of energy (National Energy Policy Development, 2001). At the same time, there is a growing recognition of the need to establish a sustainable relationship between society, resource use, and the environment (National Research Council, 1999). If the same standard of living is to be maintained in the United States as global petroleum production declines, fuel autonomy implies an expansion of national energy production and economic growth for West Virginia and other states with a rich abundance of energy resources. However, there are often large environmental impacts associated with the extraction and use of coal. West Virginia is currently caught between external and internal pressures to increase economic prosperity through further developing energy and other natural resources while also confronting the daunting task of preventing industry from further damaging the health of human beings and the environment.

Major environmental problems in West Virginia (identified by CVI through interaction with stakeholders) include sediment accumulation in streams, forest fragmentation, invasion of exotic species, acid rain, acid mine drainage and the habitat loss that accompanies such environmental change (CVI 2002). Also, flooding was identified as a major environmental threat to human life and property. Human economic activities such as mining, timbering, farming, and changing patterns of urban and industrial growth are the primary forces causing environmental change in the state. Despite this economic activity, many places in West Virginia and throughout the Mid-Atlantic Highlands experience economic problems from low per capita income to high unemployment and low labor force participation rates (CVI 2002). In this report, we examine the larger system that controls the environmental and socioeconomic characteristics of local systems within West Virginia. The emergy analysis methods used in this state-wide report can be applied to provide a context for environmental and socioeconomic problems at the local scale and to evaluate alternative solutions for watershed restoration as proposed in CVI (2002).

3.2 The Efficacy of Emergy Accounting in Answering Management Questions

People need accurate and complete financial information to answer questions about their fiscal condition, so that they can make better decisions. The kinds of questions that can be answered by keeping accurate financial accounts are many and depend on the particular system for which the accounts are being kept. For example, people ask and answer practical questions about their individual finances every day. Some of these questions relate to the financial condition of assets or income, *i.e.*, “How much money do I have in the bank?” or “Are my monthly expenditures within my budget?” Other questions relate to the equity of exchange, *e.g.*, “Is that used car really worth the money?” or “How much will the schools improve if my property taxes go up?” Still other questions are social in nature and relate to how we are doing compared to others, *e.g.*, “Do we have a higher standard of living than the neighbors?” When the questions relate to financial condition, dollars are sufficient to provide the answer. However, where resources in the public domain are being used, degraded, or developed, questions about environmental systems cannot be answered by considering economic value alone. Yet the health of society depends on accurate answers to questions about the condition and use of environmental resources as surely as individual financial health depends on assessing personal savings and income.

Standard accounting tools, such as the income statement and balance sheet, are used to document the financial health of a firm. It is no less important that we develop similar tools to assess the condition of environmental systems. Emergy accounting provides the means to keep the accounts for the economy, society, and the environment on a single income statement and balance sheet. The questions that we can answer after performing an emergy analysis of a system are similar to those that we can answer as a result of doing a financial analysis of a business or of our individual accounts. The following key questions to be answered from information on West Virginia’s environmental accounts were derived from discussions with environmental managers from the Canaan Valley Institute and the United States Environmental Protection Agency: (1) “What is the current level of economic investment in relation to West Virginia’s resource base, and is this level of investment sustainable?” (2) “What is the net exchange of real wealth between West Virginia and the nation?” (3) “What are the major causes for any observed imbalances?” (4) “What actions can be taken to address an imbalance, if it exists?” (5) “How does West Virginia’s standard of living compare to other states and the nation?” (6) “Who benefits most from the productive use of the state’s resources?” (7) “How self-sufficient is the state based on its renewable and nonrenewable resources?” (8) “How can we manage the environment and economy of West Virginia to maximize the well-being of humanity and nature in the state and in the nation?” The emergy accounts for West Virginia presented below provided information and indicators that helped answer these questions.

3.3 Narrative History of West Virginia

The facts and many insights on the history of West Virginia given in the narrative history were taken from Rice (1985) and Rice and Brown (1993). This narrative history is our condensation of these histories from the perspective of West Virginia as an environmental system.

For four hundred million years, the area that is now the Appalachian Highlands was an arm of the Atlantic Ocean and it was this water body that left behind many of the natural resources found in the Appalachian States. The biogeochemical system acting in this body of water created the vast mineral deposits of salt, oil, and natural gas in western West Virginia and limestone from the fossils of marine animals in the east. To the east of this ancient water body were highlands from which material eroded and washed down the watershed, weakening the geosyncline and causing the rock strata to be repeatedly folded and uplifted forming the ridge and valley region of the state. Prior to the final upheaval, much of West Virginia was covered by wetland vegetation. This vegetation decomposed to form peat that was then buried and subjected to heat and pressure deep in the earth. This peat was eventually transformed into the coal beds that now lie beneath two thirds of the state. Streams and erosion continued to sculpt the landscape as the periods of uplift and subsidence followed one after another in succession.

The mountainous landscape that resulted did much to affect the settlement of the state. The rough terrain and lack of a unifying river system discouraged many early settlers from coming to West Virginia because it was both difficult to enter the area and difficult for early settlers to maintain communication with friends and relatives without good transportation systems (Rice 1985). Only a few dared to face the dangers of Indian attacks and disputes over land, the loneliness of mountain isolation, and the struggles that came with conquering a wilderness alone (Rice 1985). Most families were willing to move only as part of a larger migration.

The first wave of settlers came to present day West Virginia in 1730. At this time, in an effort to protect the Virginia colonies from Indian hostilities, Virginia made land laws that offered speculators one thousand acres of land for each family they settled west of the Blue Ridge. The law stipulated that the families had to come from outside Virginia and be settled within three years. Most of the families who settled were from Pennsylvania, New Jersey, or distressed areas of Europe. This mechanism of land settlement proved to be successful because the lands of the Shenandoah and Upper Potomac Valleys were fertile and easily supported both crops and grazing. The speculators provided financing on easy terms and charged only three pounds per acre, compared to the five to ten pounds per acre charged for less desirable land in Pennsylvania and Maryland. The speculators also took care of legal matters, an important consideration for immigrants, who often had a minimal mastery of the English language and laws of Virginia (Rice, 1985). The wisdom of the Virginia legislature in requiring the settlement of families on the frontier was a key factor in the success of the land companies and the settlements they established (Rice and Brown 1993). However, land laws that were so successful in attracting the first settlers to West Virginia were to cause trouble in later years.

The Virginia Land Law of 1779 made preemption rights and claims based on military treasury warrants transferable. This enabled speculators to acquire millions of acres formerly granted to the land companies and individuals for military service. By 1805, 250 persons or groups had acquired 10,000 acres or more. Many were merchants of Philadelphia, Baltimore, Richmond, and other eastern cities. Traffic in land left much of West Virginia in the hands of absentee owners who often had more interest in exploiting the resources than in the region itself. West Virginians suffered from the land system whether their land was in dispute or not, because speculators failed to spend resources on development and waited for the state government to provide roads, canals, and improvements. Often the land was classified as “wild” and was taxed at very low rates providing little money for internal improvements, schools, and services. West Virginia also failed to require land surveys in accordance with the spherical earth. This led to layers of claims, many by non-residents, that were overlapping and vague causing land titles to be insecure. The chaotic land system deprived West Virginia of thousands of much needed immigrants and retarded economic growth. Some men and women settled in the state and fought for its improvement, but many others preferred the rich farmland and secure titles of lands further west (Rice and Brown 1993).

Early West Virginians saw the economic potential of coal, timber, iron, and other natural resources as evidenced by their use in local industries, but the absence of investment capital, lack of developed markets within the state, and problems in transportation by both land and water, prevented the large scale exploitation of the state’s natural resources. Historically, the ability to extract, use, and transport the vast quantities of energy in nonrenewable resources within the state has been the limiting factor for economic and social development in West Virginia.

Transportation infrastructure is important for economic development, especially in a mountainous state. In West Virginia, the first transportation industry was the manufacture of flat boats, which were used to carry agricultural goods and salt along the rivers. The need to move coal from the heart of West Virginia drove the small mining companies to organize the Coal River Navigation Company in the 1840s and to begin the construction of locks and dams along the rivers so that larger boats could pass to the Ohio River. The construction of railroads had an even larger affect on economic development than river improvements (Rice 1985). Railroads could be built near the resources, rather than having to transport the resources to the river, and their spread was limited only by the speed at which the rails could be laid (Rice 1985). The introduction of the railroad greatly increased the development of all resource-extraction industries in the state.

3.3.1 *Salt*

For centuries the Indians had visited the salt springs on the Kanawha River and Little Kanawha River where they used the basic technique of boiling brine to make salt. In 1797, the first commercial salt works opened in the Kanawha Valley. By 1851 there were 52 salt furnaces lining the banks of the Kanawha over a 10 mile stretch that produced 2500-3000 bushels (63625 kg) of salt per day. The industry peaked in 1846 with the production of 3,224,786 bushels (76,955,120 kg). The salt works drew hundreds of workers to make the barrels and hoop polls, work the salt, and run the flatboats needed for transportation. Thus, the salt industry produced the first diversified economic life in West Virginia. Salt making was also the first industry to radically change the social structure of the state by creating a class of exploitable industrial workers (Rice 1985).

3.3.2 *Coal*

The deposits of coal that lie beneath the surface of the land are the legacy of productive swamplands that existed at an earlier time. Exploitable seams of bituminous coal lie beneath two thirds of the state of West Virginia. For a long time West Virginia coal was used only in the salt furnaces. It was not sent outside of the state because the Kanawha River was too low for navigation by large boats during the summer and fall months. For this reason, coal was only used locally within the state in the ironworks, foundries, paper mills, glass factories, distilleries, and cotton and woolen mills. However, in 1847, cannel coal was found at Cannelton, WV. Cannel coal is a rare, clean-burning variety of coal that produced the first small coal boom in West Virginia. Only the very wealthy could afford cannel coal and the majority was shipped to Boston.

With the expansion of the railroads in the 1880s, coal production greatly increased. In 1888, Fayette County became the first county in West Virginia to mine more than one million short tons of coal annually and by1912 McDowell County was producing 13.7 million tons. About 10 to 15 per cent of the coal mined was converted to coke, although no coke has been produced since 1979. With the exception of a brief decrease during economic readjustments following World War I, coal production steadily increased until the Great Depression, rising from 69,783,088 short tons in 1914 to 139,297,146 short tons in 1929. World War II stimulated a strong resurgence and the peak production year was 1947, when 173,653,816 short tons were produced.

Surface mining also rapidly increased after World War II. In 1950 it composed only 8.8% of the coal mining, but by 1980 it accounted for 20.7%. This increase was partly due to the development of heavy equipment and new technology. This practice has been controversial because it leaves scarred hillsides, destroys wildlife habitat, increases soil erosion, degrades water quality, and increases the risk of flooding. Surface mining and the mechanization of the underground mines drastically reduced the labor force while maintaining high outputs of coal.

3.3.3 *Timber*

During the Industrial Revolution many Americans saw the removal of forests as progress. In clearing land and constructing farm buildings, the first West Virginia pioneers destroyed trees without regard for their value as timber. The first saw mill was built in 1776 and logging soon became an important business. The rivers of West Virginia were not easily navigable by large barges and initially this slowed the movement of natural resources; however timber was quickly removed from the state after the adaptation of the lock and dam systems, the building of railroads and the introduction of the band saw. Lumber companies, mainly from New York, Pennsylvania, Michigan, and Minnesota, bought most of the best timberlands in West Virginia. They usually paid 2-5 dollars per acre when at the time a single yellow poplar tree could yield 2000 board feet that sold for eighty to one hundred dollars per thousand board feet (Clarkson 1964). A band saw could cut seventeen acres of forest in a single day.

Timber production increased to 1483 million board feet in 1909. From 1870 to 1920, more than 30 billion board feet were cut (Clarkson 1964). According to Clarkson (1964), this is enough lumber to build a boardwalk 13 feet wide and 2 inches thick extending to the moon. This total does not include wood carried by streams and rivers to be cut in Kentucky or Ohio, or the millions of feet burned and wasted by the pioneers and brush fires following logging. By 1920, most of the virgin forest was removed, except for a few isolated areas of small acreage. Without forests to harvest, the jobs in the timber industry were no longer available and the population of the logging towns began to diminish. In spite of past and present efforts at reforestation and conservation, timbering and various other extractive industries have left a legacy of depleted resources, scarred terrain and fleeting prosperity.

3.3.4 *Oil*

The first important oil well in West Virginia was brought into production in 1859, shortly before the onset of the Civil War. By 1863, the year West Virginia officially became a state; there were 225 wells, each pumping on average 116 barrels of oil per day. In 1882, Dr. Israel White, a professor of geology at West Virginia University, proposed a theory that oil deposits tended to collect under great arches of rock known as anticlines. This was found to be true and led to a dramatic upsurge in oil discovery and production. The industry peaked in 1900, when 16,195,675 barrels were produced. West Virginia oil production has been in decline in the 20th century.

3.3.5 *Natural Gas*

Natural gas fields frequently coincide with oil regions. The anticlines commonly have natural gas in the upper strata, oil in the intermediate strata and water or brine in the lower region. West Virginia was relatively slow at putting natural gas to commercial or industrial use; prior to the Civil War, salt making was the only industry using it. Before 1882, most natural gas was discovered accidentally by oil and salt drillers. They considered it a nuisance and made no effort to conserve it. Unused gas flows sometimes discharged into the air for months, with thunderous sounds that could be heard for miles (Rice and Brown 1993). But by 1906, West Virginia ranked first among the states in natural gas production. As with coal and oil, the initial large numbers of small natural gas operations gave way to a few giants, *e.g.*, first the Standard Oil Company and later the Columbia Gas System, who controlled production and distribution.

3.3.6 *Limestone*

Limestone is found throughout the state, but the most valuable limestone lies along the length of the Allegheny Mountains, on the Cacapon and upper South Branch Rivers and in the Shenandoah Valley. Like many West Virginia industries, it reached its peak production in the past (1977) and output is now declining. In 1977 the output of sandstone and limestone was 10,499,000 short tons.

3.3.7 *Sand*

Sand is another important material deposited within the state. Some of the sand in West Virginia is 99.8 per cent pure silica. This coupled with the natural gas and limestone assured West Virginia an important place in the glass industry, and Wellsburg had a glass factory as early as 1813.

3.3.8 *Iron*

When the iron industry first developed, small furnaces throughout West Virginia produced bar iron, but by 1830, a facility on the Cheat River made Morgantown a center of importance for production of plows, nails, stoves, grates, and other iron products. Before the Civil War, the major iron-making centers were in Wheeling, Weirton and on the Cheat River near Morgantown. The introduction of the open hearth and Bessemer processes after the Civil War led to the development of a steel industry that had major effects on the economy of the state. By 1920, a number of smaller foundries around the state had been absorbed by several much larger operations centered at Wheeling and Weirton. Two world wars further stimulated the growth of the industry and in 1932 a large plant was built in Alloy, WV. It made more than 50 alloys used in the production of high-grade steel and ferrochrome alloy. After World War II, Kaiser Aluminum built a plant in Ravenswood on the banks of the Ohio River, presently owned by Century Aluminum, which added diversity to the primary metals industry in the state.

3.3.9 *Textiles*

Textile manufacture, like iron, dates back to colonial times in West Virginia. Before World War I, Wheeling was known for its excellent calicos, Martinsburg and Berkeley Springs were known for hosiery, Charleston for blankets, and Huntington for upholstery and work clothes. Synthetic yarns and fibers began to be manufactured after World War I. Plants at Nitro and Parkersburg made rayon from the chemical processing of raw cotton and wood pulp. A DuPont plant at Belle also produced nylon from coal, nitrogen, and water, which soon replaced silk for many purposes because of its durability.

3.3.10 *Chemicals*

The West Virginia industry with the most rapid and continuous growth in the twentieth century is the manufacture of chemicals and their by-products. The extensive brines in the Kanawha Valley and the beds of rock salt in the Northern Panhandle, along the upper Ohio River and from Ritchie to Monongahela County were instrumental in the development of the chemical companies in West Virginia. The loss of German manufactured chemicals and explosives during World War I led to the federal government's construction of a high-explosives plant at Nitro and a mustard gas plant at Belle. Also, World War II brought both Union Carbide and DuPont to the Kanawha Valley to manufacture chemicals (Rice 1985).

The valley produces bromine, magnesium, sodium, barium, ammonia, and intermediate chemical compounds that are used to manufacture rubber, plastics, rayon, nylon, and antifreeze. The industry also expanded into the Ohio Valley from Huntington to the northern Panhandle, a region which supplies coal, brine, and rock salt for the production of chlorine and carbon. The demand for chemicals during World War II caused an increase in production.

3.3.11 *Electric Power*

After World War I, electric power became an important energy source. Coal-fired plants were built in Beech Bottom, Graham Station, Riversville, Cabin Creek, Albright, Willow Island, Logan, and Denova. By 1980, most of the electric power in the state was generated by the American Electric Power System, the Allegany Power Company, and Virginian Electric and Power Company (Rice and Brown 1993).

3.4 An Energy Systems Model of West Virginia

An energy systems model of West Virginia that shows the major economic and environmental forcing functions, components and connections is presented in Figure 1. It offers a conceptual guide to thinking about the region and provides the basis for developing emergy accounts for the state. The environmental energy sources, along with the fuels, goods, and services that help make West Virginia's economy productive are shown as circles outside the system boundary. Purchased imports and exports generate monetary flows that cross the state borders in exchange for products and services. Tourists bring money into the state to spend on recreation and the federal government generates both monetary inflow (as outlays) and outflows (as taxes). The flows of energy, material, and information into, through, and out of the state are identified by the various pathways, each labeled with a subscripted k. The k's are listed and defined in Table 2, but in this paper they only identify the various pathways. In a simulation model, each k has a numerical value that determines the rate of flow of energy or materials along the pathway. The system components, *e.g.*, economic sectors, shown within the diagram are defined in Table 3. The external forcing functions for the state are listed below in developing the emergy income statement for West Virginia. External forcing functions are arranged in order of increasing transformity from left to right around the edge of the box indicating the system's boundaries. In the left hand corner, solar radiation enters the system followed by other natural energies, in the form of wind, rain, the earth cycle of uplift and subsidence and rivers. Next, the energy of fossil fuel enters, followed by material goods and services, people, government and higher social structures, such as markets.

The model components in Figure 1 include aggregated aquatic ecosystems, forests, and agriculture, which together represent the natural production systems in the state. Storages of nonrenewable environmental resources are of great significance in West Virginia. They include coal, natural gas, oil, sand, salt, limestone, and clay. Renewable resources such as soil, water, timber and agricultural production are also important. Waste is a by-product of human activity and most significantly affects the aquatic ecosystems of the state as acid mine drainage, animal waste, and human sewage. The mining of nonrenewable resources supports much of the manufacturing in the state, as well as the generation of electric power. The service and commerce sector supports recreation and tourism, which generates a significant part of the gross state product, GSP. People and households supply the labor that runs the state. The state population appears to have been in a pattern of damped fluctuation over the past 50 years, which has resulted in an overall decline from its peak of 2.005 million that was attained in 1950. The transportation sector is critical for the movement of goods and services into and out of West Virginia and in the past the transportation sector has limited the rate of economic development in the state (Rice 1985).

3.5 The Emergy Income Statement for West Virginia

The emergy income statement summarizes the major annual flows of emergy for the state. It consists of four accounts, renewable resources (Table 4), nonrenewable resources (Table 5), imports (Table 6), and exports (Table 7). Each account or table in the emergy income statement has six columns as defined in Table 1. The numbers in column one (Note) refer to the listing of calculations and assumptions in Appendix C that document the values given in column three (Data).

The annual renewable resources and production for West Virginia in 1997 are shown in Table 4. There is a corresponding table of renewable natural resources and products for 2000 in Appendix E, Table E1. The chemical potential energy of rain on land is the largest renewable emergy source received by the state. The earth-cycle emergy of uplift and erosion and the emergy delivered in the chemical potential energy of rivers entering the state are each about ¾ of that supplied by the rain. The largest source of renewable production in West Virginia is timber growth, followed by livestock and timber harvest. Overall, renewable production is only 5% of the emergy produced from mining coal.

Production and use of nonrenewable sources in West Virginia was evaluated for 1997 in Table 5 with a corresponding evaluation for 2000 in Appendix E, Table E2. Coal accounts for the largest production of emergy in West Virginia followed by electricity, 98% of which is generated from coal-fired plants. Coal supplies 48% of the emergy in the energy used within the state, followed by electricity (23%), petroleum (18%), and natural gas (10%).

West Virginia imports and exports in 1997 are shown in Tables 6 and 7. There are tables with the 2000 numbers in Appendix E, Tables E3 and E4. The largest emergy imported to West Virginia in 1997 was in the material goods entering the state. The second largest emergy inflow was in the services associated with those goods, followed by the emergy in petroleum (excluding the natural gas received at the state border). Federal government outlays do not bring emergy into the state *per se*, but generate emergy flows in the state economy when spent. Total outlays must be decreased by the amount of taxes paid to get the net effect of government expenditures.

The emergy flows generated in the state's economy as a result of the dollars spent by tourists are considered to be exports because they represent assets of the state that "flow out" or are used in proportion to the experience received. The dollars that tourist bring into the state are not accompanied by emergy *per se*, they generate flows of emergy in proportion to the state's emergy to dollar ratio when they are used to purchase products and services within the state economy. We assume that the natural, historical, and aesthetic assets of the state deliver an experience to tourists that can be measured roughly by the emergy purchased through the dollars spent in tourism. A detailed analysis of the emergy required for tourists to receive particular experience would give a more accurate estimate of the value exported; however, this labor intensive work must wait until a later time. If all 1997 tourist dollars are spent at the West Virginia emergy to $ ratio, they comprise 15% of the emergy embodied in value-added exports (see Fig. 3).

Coal accounts for the largest amount of emergy produced in and exported from the state. West Virginia also imports some coal for electric power generation, alumina for aluminum production and iron ore for steel production. Coal and electricity are the largest exports and together they account for 63% of the emergy in the state's exports.

There is a large emergy flow in the transportation of natural gas through the state as indicated by the natural gas received (Table 6) and delivered (Table 7) at state borders. These large flows indicate the forces that bind the nation as a whole into a system. Much of the gas simply flows through the state with some of it stored or removed from underground storage that is available as a consequence of past natural gas production. West Virginia produces more natural gas than it uses and we assumed that the excess was exported.

3.6 The Emergy Balance Sheet for West Virginia

The emergy balance sheet, when fully developed, provides the information needed to determine whether a human activity, institution, or system is sustainable (Campbell 2004). The balance sheet summarizes the stored assets and liabilities of the state. It has the same six columns described for the income statement. Some of the storages of natural, economic, and social capital found within the state in 1997 are given in Table 8. The stored assets for 2000 are shown in Appendix E, Table E5. Many more storages of natural, social, and economic capital and debt need to be evaluated to complete the balance sheet, *e.g.*, the emergy stored in the assets of biodiversity, culture, and economic infrastructure and the debt incurred by loss of biodiversity and natural lands. Campbell (2004) presented a theoretical basis for the definition and measurement of environmental liabilities and the use of emergy-monetary balance sheets to determine the true solvency of human endeavors and institutions. Current research at the USEPA, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, is focused on developing the methods to document environmental liabilities and the completion of several example balance sheets.

A partial or incomplete balance sheet that includes only assets, such as the one shown in Table 8, still contains useful information that documents the stored wealth available in a system. In West Virginia the natural capital stored in accessible coal reserves is two orders of magnitude greater than the second largest emergy storage, the social capital stored in the education of West Virginia's people. Considerable wealth is stored in the standing stock of trees and in the remaining natural gas reserves. Combining data from the emergy income statement and balance sheet we can project that West Virginia coal reserves will last 306 years, if the 1997 production rate continues into the future.

Table 4. Annual Renewable Resources and Production in 1997.

Note*	Item	Data J, g, $,ind/yr	Units	Emergy/ Unit sej/unit	Emergy E+20 sej	1997 Emdollars E+6 Em$
	Renewable Resources within West Virginia					
1	Sun, incident	3.07E+20	J	1	3	256
1	Sun, absorbed	2.64E+20	J	1	3	220
2	Wind Kinetic Energy	1.07E+17	J	1470	15.8	1315
3	Earth Cycle	1.39E+17	J	33700	47	3904
4	Rain, chemical potential energy received	3.32E+17	J	18100	60	5008
5	Evapotranspiration, chemical potential absorbed	1.56E+17	J	28100	44	3653
6	Rain, geo-potential on land	3.66E+17	J	10300	38	3142
7	Rain, geo-potential of runoff	6.02E+16	J	27200	16	1496
8	Rivers, chemical potential energy received	9.06E+16	J	50100	45	3783
8	Rivers, chemical potential energy absorbed	2.90E+14	J	50100	0.15	12
9	Rivers, geo-potential energy received	4.99E+16	J	27200	14	1131
9	Rivers, geo-potential energy absorbed	2.06E+16	J	27200	5.6	467
	Renewable Production within West Virginia					
10	Agricultural Products	1.76E+16	J	63000	11	924
11	Livestock				28	1475
	Beef	3.70E+15	J	680000	25	2097
	All other livestock	3.17E+14	J	792000	3	279
12	Fish Production	7.22E+11	J	1961800	0.014	1
13	Hydroelectricity	4.09E+15	J	120300	5	410
14	Net Timber Growth	2.10E+17	J	20900	44	3658
15	Timber harvest	2.29E+16	J	68700	16	1311
16	Ground water	9.49E+14	J	159000	2	126

*The notes for Table 4 can be found in Appendix C at C1.

Table 5. Annual Production and Use of Nonrenewable Resources in 1997.

Note*	Item	Data J, g, $, ind/yr	Units	Emergy/ Unit sej/unit	Emergy E+20 sej	1997 Emdollars E+6 Em$
	Fuels and renewables used in a nonrenewable manner					
17	Coal Production	4.64E+18	J	39200	1819	151573
18	Coal Used in the State	9.9E+17	J	39200	388	32340
19	Natural Gas Production	1.9E+17	J	47100	89	7457
20	Natural Gas Used in the State	1.7E+17	J	47100	80	6673
21	Petroleum Production	9.2E+15	J	53000	5	406
22	Petroleum Used in the State	2.3E+17	J	64700	149	12401
23	Electricity Production	3.3E+17	J	170400	562	46860
24	Electricity Used in the State	9.4E+16	J	170400	160	13348
25	Clay	1.51E+05	T	1.9E+15	3	239
26	Sand and Gravel	1.7E+06	T	1.3E+15	22	1842
27	Limestone	1.2E+07	T	9.8E+14	118	9800
28	Sandstone	856	T	9.8E+14	0.01	1
29	Soil Erosion from agricultural areas	4.0E+15	J	72600	3	242

* The notes for Table 5 can be found in Appendix C at C.2.

Table 6. Annual Imports to the West Virginia Economy in 1997.

Note*	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E+20 sej	1997 Emdollars E+6 Em$
30	Coal	2.32E+17	J	39200	91	7579
31	Petroleum	2.17E+17	J	64700	141	11700
32	Natural Gas (Received at state border)	1.97E+18	J	47100	928	77322
33	Iron Ore	4.41E+13	J	6.08E+07	27	2234
34	Aluminum ore, Bauxite	4.4E+13	J	1.47E+07	6	539
35	Services Embodied in the Goods	2.50E+10	$	1.2E+12	299	25000
36	Material in the Goods excluding fuels	Various	J or g	Various	948	79000
37	Services	6.2 E+09	$	1.2E+12	74	6200
38	Federal Government Outlays	1.04E+10	$	5.78E+12	601	50093

* The notes for Table 6 can be found in Appendix C at C.3.

Table 7. Annual Exports from the West Virginia Economy in 1997.

Note*	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E+20 sej	1997 Emdollars E+6 Em$
39	Coal	3.82E+18	J	39200	1497	124787
40	Natural Gas (Production exported)	6.65E+15	J	47100	3	261
41	Natural Gas (Delivered at state border)	2.08E+18	J	47100	980	81640
42	Electricity	2.35E+17	J	170400	400	33370
43	Steel	2.00E+12	g	3.38E+09	68	5633
44	Services Embodied in Goods	2.72E+10	$	1.2E+12	326	27200
45	Material in Goods	Various	J or g	Various	776	63798
46	Services	5.80E+08	$	1.2E+12	7	580
47	Migration (net)	9851	People	Various	17	1417
	Preschool	131	People	3.3E+16	0	4
	School	7052	People	9.2E+16	7	541
	College Grad	2327	People	2.7E+17	6	524
	Post-College	341	People	1.3E+18	4	369
48	Tourism	4.0E+09	$	5.78E+12	231	19266
38	Federal Taxes	6.85E+9	$	5.78E+12	396	32994

* The notes for Table 7 can be found in Appendix C at C.4.

Table 8[1]. Assets of West Virginia in 1997.

Note*	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E+20 sej	1997 Emdollars E+6 Em$
49	Forest Biomass	1.04E+19	J	28,200	2,933	244,400
50	Coal	1.42E+21	J	39,200	556,640	46,386,666
51	Petroleum	1.19E+17	J	53,000	63	5,256
52	Natural Gas	3.13E+18	J	47,100	1,474	122,853
53	People	1,816,000	Ind.	Various	3,837	315,570
	- Preschool	21,952	Ind.	3.3E+16	7	604
	- School	1,181,525	Ind.	9.2E+16	1,087	90,584
	- College Grad	383,808	Ind.	2.7E+17	1,036	86,357
	- Post-College	51,036	Ind.	1.3E+18	667	53,929
	- Elderly (65+)	159,518	Ind.	1.7E+17	271	22,598
	- Public Status	18,160	Ind.	3.9E+18	708	59,020
	- Legacy	792	Ind.	7.7E+18	61	5,082

* The notes for Table 8 can be found in Appendix C at C.5.

[1] Additional assets and liabilities evaluated in Campbell (2005) are buildings 481 E+20 sej and bonds outstanding 43 E+20 sej, both obtained by converting dollar value to emergy using 1.08 E+12 sej/$.

3.7 Overview Models and Flow Summary

Figure 2 shows an aggregated model of the environment and economy of West Virginia in 1997. It provides an overview of the emergy and dollar flows across state boundaries and gives the various natural and economic sources of the flows. The pathways on the diagram show the interaction of renewable and nonrenewable resources within the system and the exchanges of emergy and dollars that drive the state's economy. Table 9 identifies the flows of emergy and dollars shown on Figure 2. The table that summarizes the flows of emergy and dollars for 2000 is found in Appendix E, Table E6. The pathway symbols and values in Table 9 are used in Table 10 to calculate indices. The number indicated in column one directs the reader to a description of the calculations used to obtain the summary flows (see Appendix C, Table C6).

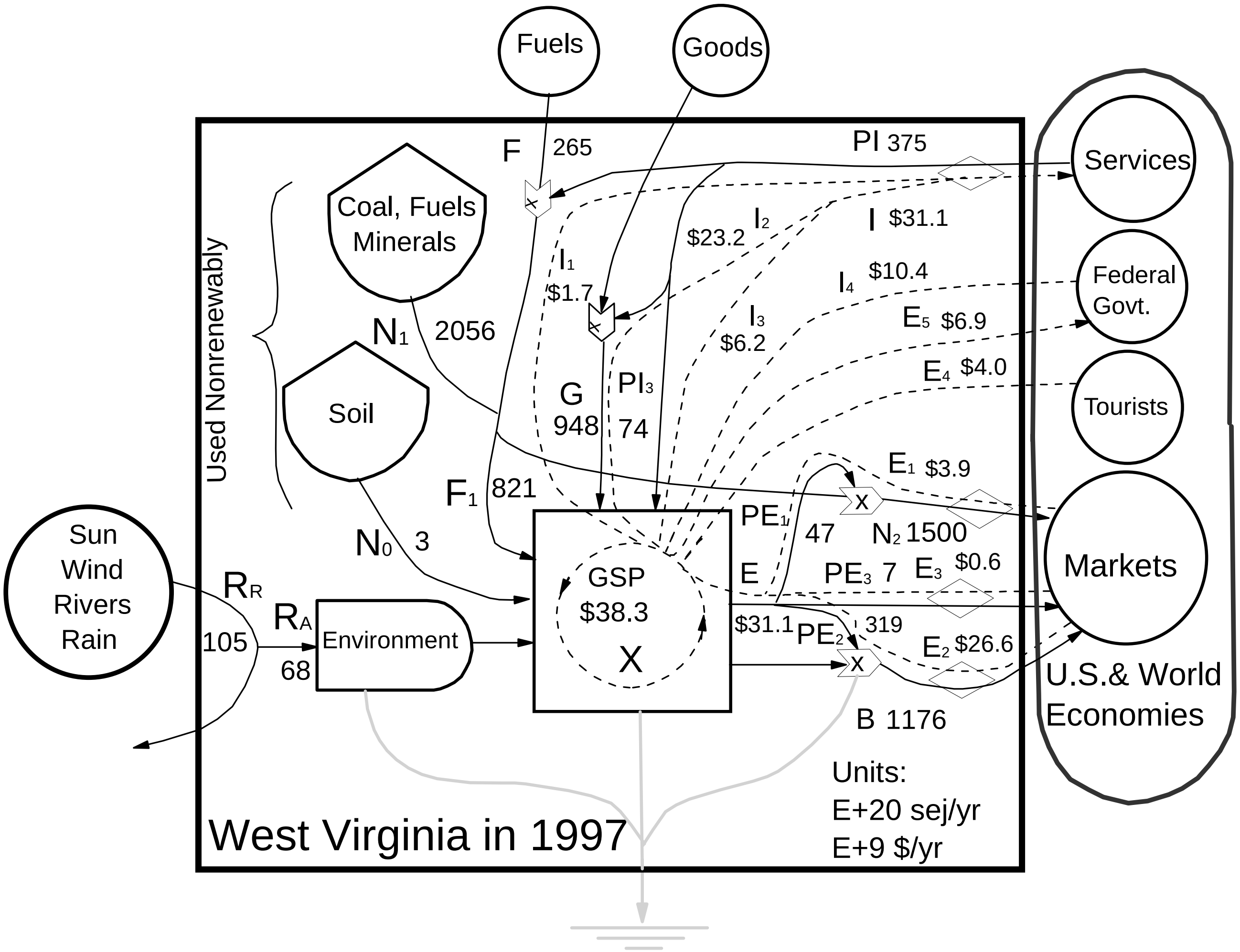

Figure 2: Aggregated diagram of West Virginia's economy and emergy resource base used for the calculation of indices. Symbols are identified in Table 9. Emergy flows times E+20 sej/y; dollar flows times E+9 $/y.

Table 9. Summary of Annual Flows for West Virginia in 1997.

Note	Letter in Fig. 2	Item	Emergy E+20 sej	1997 Dollars E+9 $	1997 Emdollars E+9 Em$
54	R_R	Renewable emergy received	105		8.75
54	R_A	Renewable emergy absorbed	66		5.50
55	N	Nonrenewable source flows	2059		171.58
56	N_0	Dispersed Rural Source	3		0.25
57	N_1	Mineral Production (fuels, etc.)	2056		171.33
58	N_2	Fuels Exported without Use	1500		125.00
59	F	Imported Minerals (fuels, etc.)	265		22.08
60	F_1	Minerals Used ($F+N_1-N_2$)	821		68.42
61	F_2	In State Minerals Used (N_1-N_2)	556		46.33
62	G	Imported Goods (materials)	948		79.00
63	I	Dollars Paid for All Imports		31.13	
64	I_1	Dollars Paid for Service in Fuels		1.72	
65	I_2	Dollars Paid for Service in Goods		23.24	
66	I_3	Dollars Paid for Services		6.17	
67	I_4	Federal Transfer Payments		10.40	
68	PI	Imported Services, Total	375		31.25
69	PI_1	Imported Services in Fuels	21		1.72
70	PI_2	Imported Services in Goods	280		23.33
71	PI_3	Imported Services	74		6.20
72	PI_4	Emergy Purchased by Federal $	601		50.08
73	B	Exported Products (goods + elec.)	1176		98.00
74	E	Dollars Paid for All Exports		31.08	
75	E_1	Dollars Paid for Fuel Exported		3.92	
76	E_2	Dollars Paid for Exported Goods		26.60	
77	E_3	Dollars Paid for Exported Services		0.58	
78	E_4	Dollars Spent by Tourist		4.00	
79	E_5	Federal Taxes Paid		6.85	
80	PE	Exported Services, Total	373		31.08
81	PE_1	Exported Services in Fuels	47		3.92
82	PE_2	Exported Services in Goods	319		26.58
83	PE_3	Exported Services	7		0.58
84	PE_4	Emergy Purchased by Tourists	231		19.27
85	PE_5	Emergy Purchases Forgone	396		33.00
86	X	Gross State Product		38.3	

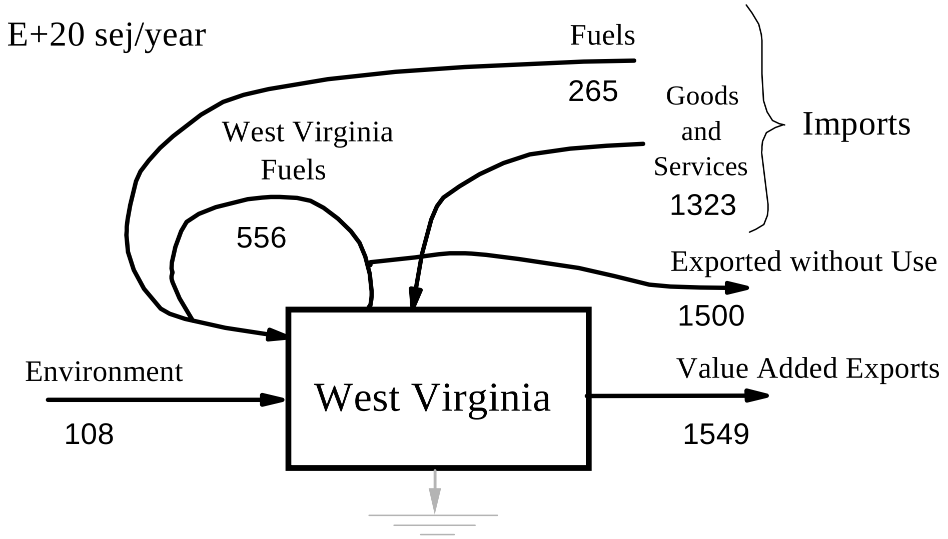

Figure 3. Summary of West Virginia's annual environmental and economic emergy flows for 1997.

The state system was further simplified using a "three-armed diagram" (Figure 3) modified to show the flows of indigenous nonrenewable fuels. This diagram gives an overview of the renewable and nonrenewable emergy base for the state, purchased imports and exports with a single, simple visual image. Several key facts that can be easily determined from the diagram: (1) West Virginia supplies 68% (556/821) of the nonrenewable fuels used within the state. (2) In 1997, almost twice as much emergy was exported as was imported (3049/1588). (3) The ratio of purchased to environmental emergy was almost 20:1 (2144/108). (4) Seventy-three percent (1500/2056) of the nonrenewable emergy produced within the state was exported without use.

3.8 Emergy Indices

Table 10 presents several emergy indices that help us gain a better understanding of the state of West Virginia. Similar indices for 2000 are shown in Appendix E, Table E7. The values of some important indices and their meaning follow: (1) Twenty-eight percent of the emergy used in the state in 1997 was derived from home sources, which indicates a moderate potential for self-sufficiency. (2) The emergy use per person was 1.22 E+17 sej/ind. This value shows that West Virginians could have a high overall standard of living (see Table 11). Later we will see why this is not the case. (3) The import/export emergy ratio shows almost twice as much emergy leaving the state in exports as is received in imports, which indicates an imbalance in the exchange of real wealth with the nation. (4) The emergy used per unit area was 3.55 E+12 sej m^{-2}, indicating that the state is developed relative to the other states in Table 11. This is somewhat surprising for a state that is 79% forested. However, this result may be explained in part by the growth trend of the nation over the time difference (1997 *vs.* 1979-1992) between the analyses. (5) The emergy to dollar ratio was 5.78 E+12 sej/$, which indicates that the purchasing power of a dollar in West Virginia in 1997 was 4.8 times that of an average place in the United States. (6) The investment ratio was 2.39, which indicates a relatively low intensity of matching (Odum 1996) between purchased economic emergy from outside the state and the emergy of renewable and nonrenewable environmental resources within the state. This index suggests that West Virginia is still an attractive place for further economic investment. (7) The environmental loading ratio was 20:1, which indicates an intense matching of purchased inputs with renewable energy from the environment potentially resulting in high stress on ecosystems or a heavy "load" on the waste processing capacity of the environment (see Table 11).

3.9 The Emergy Signature for the State

The emergy signature for West Virginia in 1997 (Figure 4) charts the significant emergy flows within the state as well as the major imports and exports. The large quantities of coal produced in West Virginia, and the high percentage of coal exported without use indicate the strength of the connection between West Virginia's economy and the larger regional economies of the East coast and Mid-West. The large emergy flows of both imported and exported goods and services and exported electricity also show West Virginia's role in the larger system of the nation. Large flows of emergy are generated when federal outlays and tourist dollars are spent in West Virginia. After the large emergy flows associated with coal production and export and the emergy flows of natural gas passing through the state are removed the largest emergy flows remaining are in the materials of the goods imported and exported. The emergy of Federal government outlays is also large, but once taxes are removed the net inflow is much smaller. The emergy of coal used to produce electricity dominates energy consumption in the state and the emergy in electricity exported is the largest single value-added export from the state. Other prominent features of the signature are large emergy inflows and outflows in the services associated with goods.

3.10 Analysis of West Virginia and Comparison with Other States

The construction of emergy indices from the accounting data on storages and flows lead to insights on the development and use of the state's natural resources. The comparison of these results with emergy analyses of other states and of the nation will help put the West Virginia numbers in perspective. Past analyses were done at various times and the analysis method has varied somewhat as it developed; nevertheless, the first order results of these studies should be comparable.

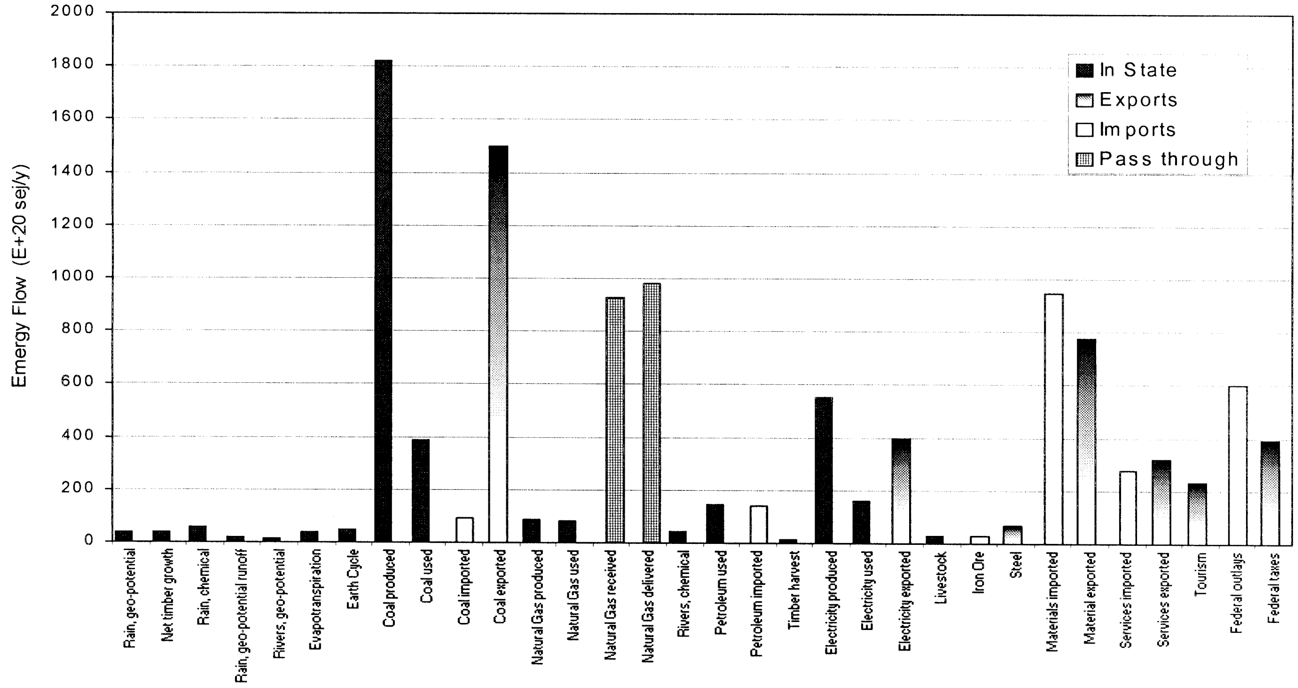

Figure 4. **The emergy signature of the State of West Virginia. Items shown to the left of steel are given from left to right in order of increasing transformity. Items to the right of steel are of high but mixed transformities. The dark gray bars show the emergy produced and used in the state, products exported are shown using striped bars and products imported are shown as stippled bars, the solid bars show the emergy of natural gas passing through the state.**

Table 10 West Virginia Emergy Indicators and Indices for 1997.

Item	Name of Index	Expression	Quantity	Units
87	Renewable emergy received	R_R	1.05E+22	sej y^{-1}
88	Renewable emergy used	R_A	6.6E+21	sej y^{-1}
89	In State non-renewable	$N_0 + N_1$	2.059E+23	sej y^{-1}
90	Imported emergy	F + G + PI	1.588E+23	sej y^{-1}
91	Total emergy inflows	R_R + F + G + PI	1.696E+23	sej y^{-1}
92	Total emergy used	$U = R_A+N_0+F_1+G+PI$	2.213E+23	sej y^{-1}
93	Total exported emergy	$B+ PE +N_2$	3.049E+23	sej y^{-1}
94	Emergy used from home sources	$(N_0+F_2+ R_A)/U$	0.282	
95	Imports-Exports	$(F+G+PI)-(B+PE+N_2)$	-1.46E+23	sej y^{-1}
96	Ratio of export to imports	$(B+PE+N_2)/(F+G+PI)$	1.92	
97	Fraction use, locally renewable	R_A /U	0.030	
98	Fraction of use purchased import	(F + G + PI)/U	0.72	
99	Fraction used, imported service	PI/U	0.17	
100	Fraction of use that is free	$(R_A+N_0)/U$	0.031	
101	Ratio of purchased to free	$(F_1+G+PI)/(R_R+N_0)$	19.9	
102	Environmental Loading Ratio	$(F_1+N_0+G+PI)/(R_R)$	20.4	
103	Investment Ratio	$(F+G+PI)/(R_R+N_0+F_2)$	2.39	
104	Use per unit area	U/Area	3.55E+12	sej m^{-2}
105	Use per person	U/Population	1.22E+17	sej/ind
106	Renewable Carrying Capacity at present standard of Living	(R_R /U)*(Population)	88,625	people
107	Developed Carrying Capacity at same living standard	8(R/U)(Population)	709,003	people
108	WV State Econ. Product	GSP	3.83E+10	$/yr
109	Ratio of WV emergy use to GSP	U/GSP	5.78E+12	sej/$
110	Ratio of U.S. emergy use to GNP	U/GNP	1.20E+12	sej/$
111	Ratio of Electricity/Emergy Use	El/U	0.072	
112	Ratio Elec. Prod./Emergy Use	Elp/U	0.254	
113	Emergy of Fuel Use per Person	Fuel use/Population	3.41E+16	sej/ind
114	Population		1.816E+6	people
115	Area		6.236E+10	m^2

3.10.1 *Characteristics of West Virginia Based on Emergy Analysis*

West Virginia is a mountainous state with an average elevation of 457 m, which is higher than all the other states east of the Mississippi River. In light of this fact, it is understandable that 33% of the renewable emergy used in the state is supplied by the geopotential energy of runoff and by rivers entering the state. Almost all the remaining 67% of the renewable emergy used in the state is contributed by the chemical potential energy of rain transpired by vegetation on the land. The Ohio River, which forms the western border of the state, and the New River, which enters the state across its southeast border, deliver emergy inflows in fresh water that are as large as the chemical potential energy of water transpired, but little of this chemical potential energy appears to be used in the state.

West Virginia is more richly endowed with fuel and mineral resources (principally coal), as measured by emergy density of underground resources, than any other state that we have studied (see Table 11) with the possible exception of Alaska. The emergy density of underground fuel and mineral resources in West Virginia is 9E+14 sej m^{-2}. This is fifty times greater than the emergy density estimates for Maine and Texas, and seventeen times that of the United States as a whole. For Alaska, the estimates of coal reserves (Brown et al. 1993) have greater uncertainty and the emergy density ranges from 0.07 to 4.84 of that found in West Virginia.

Coal dominates the emergy flows, economic activities, and ostensibly environmental impacts in West Virginia. The emergy of coal produced in West Virginia in 1997 was equal to 82% of the total emergy used in the state. Most of the coal used in West Virginia generates electricity for export; however, it is also an important input to the chemical and primary metals industries.

The production and use of coal and other products in West Virginia provides a tremendous emergy subsidy (1.46E+23 sej/y) to the larger economies of the United States and the world. Approximately, 82% of West Virginia coal production is exported without use. In addition, most of the coal consumed in the state is used to generate electrical power, of which 71% is exported. The coal exported without use accounts for 100% of the difference between the emergy exported from and the emergy imported to the state.

The United States contributes $10.4 billion dollars in total federal transfer payments to individuals and state and local governments in West Virginia. In addition, tourists spend $4 billion dollars to enjoy recreational activities in the state. Multiplying these values by the emergy to dollar ratio for West Virginia in 1997 demonstrates that the combined expenditures of the federal government could have generated an emergy flow of 6.01E+22 sej/y, if the money was spent in the state. This is 40% of the emergy in coal and natural gas that is exported without use. However, $6.85 billion are paid in federal taxes, so the net subsidy was 2.05E+22 sej/y or 14% of coal and gas exports. The net federal payments to West Virginia, when spent in the state, generate 1.63E+22 sej/y more emergy flow than if the money was spent in an average place in the United States. Thus, a dollar of government money spent in West Virginia generates a flow of real wealth that is 4.8 times greater than that generated if that dollar was spent at an average location in the United States.

Observation of road construction projects in the state plus conversations with residents indicate that the rate of economic and social development in parts of West Virginia is proceeding at an increasingly rapid pace. In the past, agriculture, commerce and industry were primarily organized by the use of resources available within valleys because transportation to mills and markets was relatively easy. Import and export of goods and services relied upon road and rail systems that were restricted to the relatively easy passages afforded by following the courses of rivers and streams, with only a few roads, often of poorer quality, connecting valley to valley. The current expansion of intra and interstate transportation corridors is causing a reorganization of the way that society uses the landscape and its resources. The valley-to-valley transportation system has improved slowly over time; however, a radical reorganization of the area and the emergy resources that existing towns and cities can draw upon to support economic and social structure is expected to accelerate with the completion of the transportation corridors currently under construction. The rapid growth that is expected to accompany this process is already under way in the valley of the South Branch of the Potomac in the towns of Moorefield and Petersberg.

3.10.2 *Comparison with Other States*

One way to determine West Virginia's status relative to other states and the nation is to compare emergy indicators and indices. Indices that are related to system characteristics such as self-sufficiency, sustainability, and equity in the exchange of real wealth (emergy) are of particular interest to society because they are related to the well-being of environmental systems. Table 11 contains comparisons of indices calculated for West Virginia in 1997 and for North Carolina, Alaska, Arkansas, Texas, Maine, Florida, and the United States determined for various earlier years. To characterize West Virginia's position relative to other states and the nation, several indices merit further attention. However, the indices and results from the 6 earlier state studies are not exactly comparable with the West Virginia study, because the earlier state analyses given in Table 11 were preformed using data that spans a period of 18 years and the methods used have varied somewhat over this time. We will have a stronger basis for comparative analysis when a present study of 7 additional states for the base year 2000 is completed.

The <u>import/export balance</u> of emergy flows shows the relationships of dependence and exploitation between trading partners. In a system where all trade is equitable, the emergy exchanged will be approximately equal. West Virginia, Texas, Alaska and Arkansas export more emergy in products and services than they import, while North Carolina, Maine, Florida, and the nation import more than they export. The ratio of exports to imports for West Virginia is similar to Texas and Arkansas but much less than Alaska. The excess emergy (imports – exports) leaving West Virginia is about 75% of the excess for Texas and Alaska and 220% of the Arkansas excess. The emergy gain to the nation from its trade with West Virginia is large as evidenced by the *emergy exchange ratio* (EER) for coal. West Virginia exported 1497 E+20 sej of coal in 1997, for which it received $3.92 billion dollars. The emergy exchange ratio for West Virginia coal in this year was:

$$(1497 \text{ E+20 sej/y}) / [(\$3.92 \text{ E+9})(1.2 \text{ E+12 sej/\$})]$$
$$= (1497 \text{ E+20 sej/y}) / (47 \text{ E+20 sej/y}) = 32{:}1$$

Thus, the buyer of West Virginia coal receives 32 times the benefit in real wealth compared to the emergy buying power of the money paid for the coal, if that money is spent at an average location in the United States. If the money is spent in West Virginia, the advantage to the buyer would be 6.6:1. In either case, West Virginia coal provides a large flux of real wealth to support growth in the national and regional economies. For comparison, Saudi Arabian oil at $40 per barrel when exchanged for US dollars yields 8:1.

The <u>emergy use per unit area</u> is indicative of the average intensity of development in a state. The annual emergy use per square meter in West Virginia is higher than in any of the other states examined in Table 11. Seventy-nine percent of the state's land area is covered by forests, much of which is on mountainous terrain, so the emergy density number is surprisingly high. In part, this result may be due to economic growth in the nation as a whole, during the 18 year period over which these analyses were performed. Also, the more complete method used to account for imported emergy may have contributed to the high empower density. However, the intense industrial utilization of coal to generate electrical power for consumption outside the state and to support chemical manufacturing, steel production, and other export industries results in high empower densities in certain areas. This tendency to spatially concentrate the industrial use of coal power is further magnified by the relatively small area of flat land in West Virginia Thus industry is found to be heavily concentrated in narrow valleys, *e.g.*, as in the Kanawha Valley and along the Ohio River, and the overall result is an average empower density equivalent to that expected in a developed state.

The <u>renewable emergy base</u> for a state sets limits on the level of economic activity that is sustainable without subsidies from outside. West Virginia can support 4.9% of the present population at the 1997 standard of living using its renewable resources alone. If the 1997 standard of living is adjusted by removing exported electricity from total emergy use, 5.8% of the population could be supported. This percentage is lower than the national average of 9.8%. Florida and Maine can support 17.3% and 33%, respectively. West Virginia's large coal reserves will allow larger populations to be supported at the 1997 standard of living until the reserves run out, which will be around 300 hundred years in the future at the current rate of use.

The investment ratio is an indicator of the competitiveness of a state in attracting additional investments. Lower ratios are more attractive for future development. The investment ratio in West Virginia in 1997 was 2.39:1 compared to an average ratio of 7.0:1 for the United States as a whole (Odum 1996). In contrast, the environmental loading ratio was 20:1, which is the highest of all the states in Table 11. This ratio indicates that economic activities are probably putting a large stress or load on the environment of West Virginia. However, the higher value may be due, in part, to differences in the methods used to determine the renewable emergy base of the states.

The fraction of use from home sources was 0.28 in 1997. Only Florida and North Carolina were more dependent on the national economy. This fact was also evident from the fraction of total use that was purchased outside the state (0.72).

The emergy use per person is considered to be an indicator of the overall quality of life experienced by the people of a nation or state. The emergy use per person in West Virginia was very high, only Alaska's use per person was higher. As previously mentioned this index usually indicates the standard of living of an average person; however, if for some reason the benefits of emergy use in the state are not transferred to the people, the total emergy use per person would not be an accurate indicator of the standard of living experienced by the people. The emergy use per person was still high (1.0 E+17 sej/ind) after the emergy of exported electricity was removed. If the emergy use per person index was broken down into the emergy of raw materials and services supporting industry and the emergy in materials and services supporting households, a better correspondence with West Virginia indices of social welfare might be found.

The emergy to dollar ratio for West Virginia was 4.8 times that of the United States in 1997. This indicates that in 1997, a dollar spent in West Virginia purchased about five times the real wealth in products and services compared to a dollar spent in an average location in the United States. Areas with a high emergy to dollar ratio can attract tourists and new businesses. The emergy to dollar ratio of West Virginia is similar to that of Maine in 1980, a state where tourism is a large part of the economy. The emergy to dollar ratio also indicates how much West Virginia losses or gains on average when it trades with various partners (see emergy exchange ratio and the coal example above).

The ratio of the emergy in the electricity used to total emergy use is an indicator of the high quality energy in people's lives. This indicator of the standard of living was lower than all the other states examined except Alaska (0.006). In 1997, this ratio was 4 tenths of the value obtained for the United States based on an analysis of conditions in 1983 (Odum et al. 1987). In West Virginia, a large amount of emergy is being used per person, but the standard of living is not perceived as high by residents and in fact has been shown to be low based on the socioeconomic data (CVI 2002).

3.11 Summary of Findings as Related to Management Questions

The findings of the West Virginia emergy evaluation provide understanding and data to address the management questions presented above. Here the question is repeated and then relevant information from the analysis is presented.

(1) "What is the current level of economic investment in relation to West Virginia's resource base, and is this level of investment sustainable?" West Virginia's low investment ratio (2.39:1) and high environmental loading ratio (20:1) show that it is in a precarious position as a state with abundant non-renewable resources to support further economic development while currently suffering from the degradation of its renewable resources due to past

and present economic activities. Even though environmental resources support intense economic development in parts of the state, West Virginia's stored wealth is so great that development pressures can be expected to continue and increase in the future. Flat land is limited in West Virginia, which may in part account for the intensity of economic development in localized areas. Without major programs to restore and protect the environment, it is unlikely that further industrial development will result in an improvement in the overall quality of life experienced by most West Virginians. Only 5% of the current population can be sustained at the 1997 standard of living on the state's renewable resources alone.

(2) "What is the net exchange of real wealth (emergy) between West Virginia and the nation?" Emergy accounting shows that West Virginia has great real wealth in natural resources and supplies a large emergy subsidy to the nation in trade. West Virginia exports nearly twice (1.92:1) as much emergy as it receives in return, resulting in an imbalance of 1.46E+23 sej/y, which is 2/3 of the annual emergy used in the state. In contrast, the monetary exchange between West Virginia and its trading partners is nearly balanced. The ratio of the monetary value of exports to imports is 0.998:1 (Table 9).

(3) "What are the major causes for any observed imbalances?" The emergy of coal exported without use (1.497E+23 sej/y) accounts for all of the difference between imports and exports in the state. Thus, the emergy inflow to and outflow from the state would be close to balanced, if coal exports were excluded form the calculation. Therefore, the costs and benefits of coal mining to West Virginia and to the nation might be considered as a distinct issue. The economic benefits derived from coal along the eastern seaboard and in West Virginia are balanced by the considerable environmental cost of extraction and processing that is born primarily by West Virginia. The environmental damage done in the state as a result of coal mining was not evaluated in this study, but it will be addressed in future research.

Table 11. Comparison of Emergy Indices for Several States in the U.S. All flows X 10^{21} sej/y unless otherwise indicated.

Index	W. Virginia[1] 1997	N. Carolina[2] 1992	Alaska[3] 1985	Arkansas[4] 1992	Texas[5] 1983	Maine [6] 1980	Florida[7] 1979	US[5] 1983
Renewable Use received/absorbed	10.5/6.6	19	404	19.8	39	15.1	66.2	773
In State Non-renewable use	55.6	0.2	220	58.2	249	3.4	2.1	5346
Imported Emergy	158.8	150	13	56.7	307	27.8	284	1936
Total Emergy Inflows	169.6	220	417	76.5	595	46.3	352	8055
Total Emergy used	221.3	190	444	135	628	46.3	380	7887
Emergy used from home sources, no units	0.28	0.21	0.97	0.58	0.84	0.4	0.18	0.75
Exported emergy including fuels	304.9	66	240	123	501	16.3	95.7	870
Imports-Exports	-146	49	-200	-66.4	-194	11.5	188	811
Ratio of export to imports, no units.	1.92	0.67	13	2.17	1.6	0.59	0.34	0.58
Fraction used, locally renewable, no units	0.030	0.10	0.92	0.15	0.06	0.33	0.17	0.1
Fract. of use purchased outside, no units	0.72	0.79	0.03	0.42	0.37	0.6	0.75	0.25
Fraction of use that is free, no units	0.031	0.21	0.92	?	0.12	0.33	0.18	0.22
Ratio of purchased to free, no units	19.9	3.74	0.10	0.73	7.3	2	4.2	3.5
Area m^2	6.24E+10	1.36 E+11	1.49E+12	1.35E+11	7.00E+11	9.40E+10	3.10E+11	9.40E+12
Population, individuals	1.8E+06	6.9 E+06	5.E+05	2.E+06	1.57E+07	1.13E+06	8.80E+06	2.34E+08
Use per unit area, sej m^{-2} y^{-1}	3.55 E+12	1.39E+12	3.00E+11	9.98E+11	9.00E+11	4.90E+11	1.20E+12	8.40E+11
Use per person, sej $ind.^{-1}$ y^{-1}	1.22E+17	2.70 E+16	9.10E+17	5.64E+16	4.00E+16	4.10E+16	4.30E+16	3.40E+16
Renewable Carrying Capacity, individuals	8.86E+04	6.8 E+05	4.5E+05	3.46 E+05	9.80E+05	3.70E+05	1.53E+06	2.30E+07
Developed Carrying Capacity, individulas	7.09E+05	5.44 E+6	3.56 E+06	2.77 E+06	7.80E+06	2.90E+06	1.23E+07	1.83E+08
Ratio of emergy use to GSP, sej/$	5.78E+12	1.19 E+12	2.30E+13	3.45E+12	2.60E+12	5.00E+12	4.30E+12	2.40E+12
Ratio of Electricity: Emergy Use, no units	0.072	0.29	0.006	?	0.18	0.22	0.23	0.17
Fuel Use per Person, sej/individual	3.41E+16	1.6 E16	5.10E+16	?	2.90E+16	2.20E+16	2.30E+16	1.50E+16
Environmental Loading Ratio, no units	20.4	9.14	0.10	5.80	10.31	2.45	4.74	9.20
Renewable Empower Density sej m^{-2} y^{-1}	1.7 /1.1 E+11	1.40 E+11	2.71 E+11	1.47 E+11	5.57 E+10	1.61 E+11	2.14 E+11	8.22 E+10

[1]This study, [2]Tilley (1999), [3]Brown et al. (1993), [4]Odum et al. (1998a), [5]Odum et al. (1987), [6]Campbell (1998), [7]Odum et al. (1986a, 1998b), [5]Odum et al. (1987)

(4) “What actions might be taken to address an imbalance, if it exists?” Federal outlays to a state are an obvious way to address trade inequities. West Virginia receives $3.56 billion in net transfer payments (outlays – taxes) from the federal government. This money makes up about 14% of the existing emergy deficit when converted to emergy using the West Virginia emergy to dollar ratio. The question of the equity of exchange between West Virginia and the nation could be further resolved using emergy methods to systematically consider all the benefits and costs accruing to both the state and the nation as a result of their relationship. This work must be left to a later time.

(5) “How does West Virginia’s standard of living compare to other states and the nation?” Quality of life as measured by the emergy use per capita appears to be high, but many social indicators are depressed (CVI 2002). This paradoxical condition can occur if the benefits of high emergy use fail to reach the majority of people because of unusual or anomalous conditions. Three such conditions exist in West Virginia, which may explain the paradox: (a) the limited availability of flat land causes much of the emergy used in the state to be concentrated in a few heavily developed industrial areas and power generating centers; (b) 71 percent of the electricity generated in West Virginia is exported and thus electricity does not contribute to the quality of life experienced by West Virginians to the same extent as in other developed states; (c) 58 percent of the people live in rural areas far from the industrial centers. The ratio of the emergy in electricity consumed to total emergy use shows the standard of living in West Virginia to be 1/3 of the average for the U.S., NC, ME, TX, and FL. Social and economic quality of life measures (CVI 2002), *e.g.*, the state was 49th in per capita income in 1997, reinforce the picture given by electricity use.

(6) “Who benefits most from the productive use of the state’s resources?” The 1997 CFS shows that over 53% of the value and 63% of the tonnage (largely determined by coal) of West Virginia’s exports goes to destinations on the Eastern seaboard from New York to North Carolina and to Ohio and several other Mid-Western states *(2)*. In addition, the majority of the electricity generated in West Virginia is exported to Virginia and other states. Thus, much of the real wealth produced in West Virginia supports the higher standards of living found in surrounding regions. Also, the benefits of past economic activities within the state, *e.g.*, timbering and mining, have not contributed proportionately to the standard of living of the people of West Virginia, when compared to many other states and the nation (see 5 above). Absentee ownership of much of West Virginia’s vast coal and timber resources appears to have been a factor in the historical impoverishment of the state (Clarkson 1964, Rice 1985). The bottom-line of this analysis is that, at present as in the past, more real wealth is taken from the environment and people of West Virginia than is returned to them.

(7) “How self-sufficient is the state based on its renewable and nonrenewable resources?” The emergy indices of self-sufficiency (emergy from home sources) and dependence (fraction of use purchased, fraction purchased service) presented above are accurate but only show one aspect of West Virginia’s relationship with the nation and surrounding regions. The large emergy flows, which West Virginia supplies to the surrounding economies, are not used to calculate the fraction of use from home sources or the fraction of use in imported services (Table 10). Removing the large emergy exports in coal and electricity from the exchange balance makes West Virginia look like a typical emergy importing state such as Maine or North Carolina, which have similar support from home sources (Table 11). Without the coal and electricity exports, imported emergy exceeds export by 15%. Paradoxically, West Virginia provides energy independence and a high standard of living to its neighbors by sending coal and electricity to the surrounding regions while the state’s economy is very dependent on the national economy and many West Virginians live in poverty. The State’s potential for self-sufficiency in a lower energy future (Odum and Odum 2001) may be more accurately shown by the fact that at least 62% of 1997 fossil fuel energy use in the state was supplied from home sources and that 82% of the coal mined was exported. With coal reserves that will last 300 years at the current rate of use, in the future West Virginia is potentially one of the nation’s more self-sufficient states.

The eighth question "How can we manage the environment and economy to maximize the well-being of humanity and nature?" relates directly to the decision-making criteria for environmental managers. Financial managers have a clear criterion for overseeing the operations of a business, which is to maximize profits and shareholder value. Energy Systems Theory provides a parallel maximal principle, which managers should consider in making decisions on environmental policy. In this method, policy outcomes are compared based on the total environmental, economic, and social emergy flows realized under each alternative. The maximum power (empower) principle (Lotka 1922, Odum 1996) indicates that those systems which maximize empower in their networks will be the ones that prevail in evolutionary competition with alternatives. Emergy accounting and energy systems model simulations allow managers to quantify the empower relations among environmental systems with alternative designs. Maximizing empower for the entire system gives a clear unified criterion for decision making and provides an answer to the eighth management question given above. The use of this criterion in environmental decision-making may help society avoid the expense of costly trials and errors, which are often required under present decision-making methods such as adaptive management.

3.12 Recommendations to Managers

Constructing emergy accounts for the State of West Virginia gave us quantitative and comparable information to judge the condition of the economy and environment in the state and to answer management questions. Emergy indices helped us understand the current condition of the state and how we might set policies to improve conditions there. Based on past emergy analyses and the insights gained from this study, we propose that the methods and principles of emergy accounting presented in this report and in Odum (1996) be used to keep consistent and accurate books for environmental systems. A possible course for the further development of methods and tools in environmental accounting using emergy might parallel the present methods and models used in bookkeeping and accounting (Campbell 2004). If emergy accounting methods continue to develop and become generally accepted, independent emergy audits of environmental systems may become a regular part of a system of checks and balances governing humanity's relationship with the environment.

3.13 West Virginia and the Future

No system on earth exists alone. According to the maximum empower principle (Lotka 1922, Odum 1996), they all have developed interactions with the net result that empower (emergy per unit time) moves toward a maximum for any given set of external forcing energies. The maximum power principle implies that human as well as natural systems become coupled to this end. The mountain areas of West Virginia are coupled to the coastal plains of Virginia, Maryland, and Louisiana through water and sediment movements just as the flow of West Virginia exports and imports couples the state economy with the Eastern and Mid-West regions and with the nation. Energies of many kinds are exchanged within these systems and all components, and the system as a whole, should be better off in the long run as a result of this process. However, when the external emergy sources to that system are changing, it often takes some time for emergy flows to be maximized throughout the system. For this reason, emergy analysis can help discern where the patterns of interaction may be improved (by elucidating conditions that increase emergy flow) toward the end of attaining greater benefits for the system as a whole. Achieving an equitable balance of emergy exchanges among the system components may point the way toward higher empower for the whole.

In the future, as world oil production reaches its peak and declines (Campbell and Laherrere 1998), the United States will become more dependent on the remaining deposits of fossil fuels, such as West Virginia coal. West Virginia can prepare for the challenge of meeting larger demand for its energy and environmental resources, by using emergy accounting methods to evaluate the environmental and socioeconomic costs and benefits associated with current economic production systems, energy technologies, and development plans to determine what alternative system designs lead to social and economic prosperity and are also sustainable, *i.e.*, compatible with maintaining a healthy environment. The emergy accounts and indices presented above are a beginning.

Section 4

Discussion

The publication of “Environmental Accounting: Emergy and Environmental Decision Making” by H.T. Odum in 1996 made the methods of Emergy Analysis easily available to the broader scientific community for the first time. These methods make it possible to keep “the books” for an environmental system, including accounts for the economic, ecological, and social components of these systems, in common units of solar embodied joules (sejs). Despite the promise that some scientists see in emergy methods, the scientific community as a whole has been slow to recognize this potential.Tests of the method and comparison of results to other methods have been infrequent; and therefore, the potential benefits of adding emergy accounting to the tools commonly used by environmental managers have been foregone. One purpose of this technical report is to make emergy methods and data sources easily accessible to ecologists, economists, and managers within and outside the EPA in a peer reviewed government document, so that they might be more widely tested and applied in finding solutions for practical problems encountered in managing the complex systems of humanity and nature. A second purpose was to present the results of an emergy analysis of West Virginia and to test the efficacy of these methods by addressing questions that environmental managers had about economic and environmental conditions and policies for the state as a whole.

The methods of emergy accounting are relatively new and still developing, but we believe that they possess great potential as a tool to aid environmental decision-making. Several advances in the method have been presented in this study: (1) We made the analogy between emergy accounting and financial accounting and bookkeeping explicit by proposing the use of emergy income statements and balance sheets as the standard tools of environmental accounting (Campbell 2005, Campbell et al. 2004). (2) We found formerly unused data sources and revised the method for evaluating imports and exports to and from states in the United States, making it possible to construct accurate accounts for these important fluxes. (3) We refined and clarified existing methods of emergy analysis by distinguishing clearly between the renewable emergy received and the renewable emergy absorbed in the calculation of indices. (4) We calculated several new transformities (Appendix B) and estimated rough transformities for commodity classes in the Standard Classification of Transported Goods (SCTG).

4.1 Standard Method Versus Intellectual Creativity

The methods of emergy analysis have evolved over the past 30 years (Odum 1971, 1983, 1996) and the vitality and creativity of new insights and ideas have played an important role by creating a general and flexibile method. Unfortunately, this has caused the method to vary over time. For example, previous emergy analyses for the states of Florida (Odum, et al., 1986, Odum et al. 1998b), Texas (Odum, et al., 1987), Alaska (Brown et al., 1993), North Carolina (Tilley, 1999), Arkansas (Odum et al. 1998a), and Maine (Campbell, 1998) have each added new insights and ideas to the method for analyzing states, but differences in the method make the results of these analyses, done over many years, only good for first order comparisons. It is not our intent to limit the future development of emergy analysis methods; however, standards for the emergy analysis of states and other systems are needed to make results comparable and to ensure that anyone can use the proposed tools to reproduce results. We hope that the material presented here makes the method for constructing the emergy accounts for states transparent and reproducible to all those who choose to use and improve it. To this end we included extensive notes in the appendices that document the calculations of the entries on the emergy tables. Appendix D is devoted to a detailed description of the method that we used to determine emergy imports and exports. We also include an appendix that documents the sources for all the transformities used and the calculations for the new transformities that were determined in this study.

4.2 Methods Developed and Refined in This Study

The renewable emergy base for a system is an important characteristic that has been determined using various rules over the years. The objective in calculating this quantity is to determine the degree to which the renewable energy sources of the earth have been concentrated in a particular area without double counting any of the inputs. The renewable emergy delivered to the system boundaries is received by the system. The part of the renewable emergy received that is absorbed is most important because it is the emergy actually used within the system to make products and services. The mutually supporting role of the various kinds of energy transformed in the system has been clearly demonstrated by the complementary interactions of the geopotential energy of runoff and the chemical potential energy of evapotranspiration working together to structure landscapes (Romitelli 1997, Odum et al. 1998a, Brandt-Williams 1999). In this study, the renewable emergy received (R_R) and the renewable emergy absorbed (R_A) were clearly distinguished in definitions and in the calculation of indices. We think that it is important to distinguish these two quantities because the transformity of the system and its products are a consequence of the energy used in that system, whereas, the energy received by the system indicates the potential of the system for development, *e.g.*, the amount of emergy received may determine the attractiveness of an area for investment and future development. For example, potentially, all the river water entering a state can be used to support economic activities within the state. In some cases almost all the emergy received is used in the system, nevertheless, we believe that these two quantities should be distinguished in future calculations of emergy indices that use the renewable emergy base for the system.

The method for calculating the imports and exports to and from a state in the United States was revised to use data from the U.S. Census Bureau's Commodity Flow Survey for 1997 (this survey was updated in 2002 but this data was not available at the time of the study). This revised method resulted in a major improvement in accuracy over the first method that we used to determine the imports and exports to and from the state's economy. More complete accounting data caused the ratio of exports to imports for West Virginia to decrease from 8:1 (this ratio was found in a preliminary determination using North American Free Trade Agreement (NAFTA) data on trade with Canada and extrapolation techniques) to 2:1. The difference was due to a more accurate determination of the emergy coming into the state in the materials of imported goods, which was formerly one of the most uncertain numbers in the analysis.

4.3 Quality Assurance: Reliability of the Data and Uncertainty

One question that should be asked of any scientific analysis is, “How do we know that the results reported are correct and accurate?” This question is particularly relevant for extensive and/or complex analyses that draw upon many sources of data. In common usage, the word “uncertain” means that something is unknown or doubtful; however, in scientific language “uncertainty” pertains to the probability structure of the data. For, example, a relevant variable such as rainfall can be expressed as the mean of a normal distribution plus or minus its standard deviation. Reporting the probability structure of the data always provides more information and may in some cases (e.g. risk analysis) allow better decisions to be made. It requires a considerable amount of extra work; however, to obtain probability distributions for all data in an extensive analysis, and the time and effort required to obtain this information may not be worth it, if the variation is small or for some other reason not important. In emergy analysis there is often a great diversity in the amount and kind of information available on the various numbers used in the analysis. For this reason, emergy accounting provides 1st order answers to questions on the scale of the analysis. If more exact answers are needed, the scale of the analysis can be reduced by using a smaller window in space and time to set the system boundaries. As a rule of thumb, emergy analysts aim to achieve estimates that are within 10% of the actual value of the variable used in the analysis. Some numbers will be determined with a higher degree of accuracy, but others may be accurate only to an order of magnitude. Because many systems are characterized by dominant energy flows that exceed the less important flows by an order of magnitude or more, a first order estimate of quantities is usually sufficient to produce a robust analysis. Many emergy analyses have been performed over the past 20 years and numerous errors have been found and corrected in these analyses, but the results of an emergy analysis are rarely changed by subsequent corrections.

Over the past three years, many versions of the West Virginia emergy analysis have been produced; in this process errors have been found and corrected and the methodology has been improved. The history of changes in values and indices in this report is used to illustrate the sensitivity of emergy analysis to error correction and improvements in methodology. In addition, the relevant characteristics of the different types of data are reported and an explanation of the techniques used to check and ensure the accuracy and quality of the numbers used in the analysis is given.

Two sources of uncertainty are considered (1) uncertainty in the numerical values of the quantities used in the analysis and (2) uncertainty in the methods and models used to make determinations. Uncertainty in the numerical values of the data arises from imprecision of the measuring device, scanty or unrepresentative data, and systematic flaws in the measuring process (Finkel 1990). Model uncertainty arises from difficulties in determining which quantities are relevant to the analysis, from the technical methods used to determine those quantities, and from the choice of surrogates when the needed information is not directly available.

Both environmental and economic data are key inputs to emergy analyses. The broad data quality objective for these data is that values be determined to within 10-15% of the actual value with a high degree of confidence. Environmental data is generally determined to within 10% and meets our data quality objectives. For example, pyroheliometers measure incident solar radiation with 2-5% accuracy, anemometers measure wind speed within about 5% and rain gauges record precipitation within about 10%, but newer electronic instruments claim ±3% accuracy.

The Energy Information Administration (EIA) provided key data on energy production, consumption and movements. The EIA obtains data from survey forms, some of which are statistical samples, as well as from many additional information sources *(42)*. They report both sampling and non-sampling errors in their surveys, and have extensive procedures in place to guarantee data quality. In some cases, almost all participants in a process are counted. In 1997, for example, EIA documented 1850 coal producers who reported production, which included all U.S. coal mining companies with production of 10,000 short tons per year or more. In most cases, EIA data meets or exceeds our data quality objectives.

Commodity Flow Survey (CFS) data was critical in the development of a revised method for calculating the import and export of emergy to and from a state. The CFS is a survey conducted every five years by the U.S. Census Bureau. Both sampling and non-sampling errors are considered, and the reliability of the data is reported as the coefficient of variation with its standard error. The CFS data meets or exceeds our data quality objectives for total commodity movements. For example, the dollar value of inbound shipments to West Virginia was determined within 6.2% and the tonnage value within 7%, whereas, the dollar value of shipments leaving the state was determined within 2.6% and tonnage leaving within 11.8%. In general, the estimated movements of individual commodities have higher uncertainties. In summary, we have a high degree of confidence that the total material, energy, and monetary flows upon which the energy and emergy calculations of imports and exports depend have been determined within 10 - 15% of their actual values.

Whenever the opportunity has arisen, we have used duplicate data and different calculation methods to check the accuracy of estimates. For example, the EIA information on coal imports and exports was used to check the CFS estimates of these quantities. Petroleum imports from the CFS were checked against the petroleum imports that were required to meet the difference between instate production and consumption obtained form the EIA data. Potential temporal anomalies in the economic data were assessed through collecting and comparing socioeconomic data for two years.

Long term averages (10-50 years) are used for environmental variables. In this case, the variation is not reported because most socioeconomic systems depend on the long term average environmental conditions for support and development. Trends or variations in the long term data would be considered as a part of a dynamic energy systems model analysis of the state (not performed in this study).

The effects of our improvements in the methodology for estimating imports and exports have already been mentioned above. The change realized may be somewhat greater than what would be expected for a mere refinement in methodology because our first method had not been proven and it used NAFTA data that proved to be a poor surrogate for the more accurate CFS data set. In general, everything that is known to be of importance in the system under analysis is included. The emergy associated with each item is an indicator of its relative importance and determines whether an item is included in the analysis.

The effect of correcting an error in the determination of the energy associated with and an input is illustrated by the recalculation of the geopotential energy of runoff absorbed by the system. In Campbell et al. (2004), this number was incorrectly calculated, because the energy used was determined relative to sea level rather than the minimum elevation of rivers leaving the state. When this number was corrected, the energy absorbed changed from 6.59 E+16 J/y to 6.02 E+16 J/y, a difference of 8.6%. This resulted in a change of 2 E+20 sej/y or 2.9% in the emergy absorbed by the system and a change of 0.0008 or 2.9% in the fraction of use that is locally renewable, which is an important index calculated using the renewable emergy absorbed. Other calculations that have been refined have resulted in a similar or smaller percentage change in the energy, emergy, and emdollar values. The large change in the ratio of imports to exports was based on a 30% decrease in the difference between emergy imported and emergy exported. The major conclusion that West Virginia is a net exporter of emergy was unchanged by methodological improvements and the correction of errors in calculations.

The transformities and specific emergies by which the energy or mass flows are multiplied, respectively, to obtain emergy are critical numbers in the analysis. Campbell (2003) analyzed five global water budgets, and determined that the transformities of global hydrological flows, such as rain, evapotranspiration, and river flow, were determined within an average standard deviation of 5.9± 2.5% of the mean value. These global transformities meet our data quality criteria for emergy analysis. Multiple determinations of transformities are not often available, and an accurate estimate of the differences that arise from different sources of data and different estimation techniques is not available for most items. In a few cases, multiple determinations of transformities using different methods have been carried out. Odum (1996) determined the transformity of coal from its relative efficiency in producing electricity and from its geological production process. The former method gave an estimate of 4.3E+4 sej/J and the latter 3.4 E+4 sej/J. The two values are within 12 % of the mean value, which may be a rough estimate of the model uncertainty in determining transformities. Appendix B documents the transformities used in this study and gives sources for the original determinations. In addition, the calculations for the new transformities determined in this study are given in this appendix.

We estimated the transformity for each SGTG commodity class to determine the emergy in the tonnage of each commodity imported. These transformities are approximated by averaging known transformities of items within the class (without services); however, all items in a class are not included in the determination of the transformity. In some cases, when a transformity is not known for any item in the class, the parent material is used as a surrogate for the item’s transformity. The use of parent materials results in a minimum estimate of the emergy imported and exported in these commodity classes. More work is needed to calculate additional transformities and to obtain better estimates for known transformities using multiple data sets and different calculation methods to determine the distribution of values.

4.4 Future Research and Reports

The methods described in this report represent a significant step forward in our ability to perform accurate and comparable emergy analyses of states within the United States. Comparable state analyses provide the raw material for the analysis of regions, which is of particular concern to the USEPA and other government agencies that are responsible for the management of environmental, social, and economic conditions in regional areas, e.g. EPA Region 3, the Mid-Atlantic Highlands, The Chesapeake Bay watershed. There are emergy analyses for seven additional states in various stages of completion as this report is being written. The five states of the Mid-Atlantic region (WV, VA, PA, MD, and DE) are among the eight states analyzed and an emergy analysis of this region is planned in the future. In addition, the emergy accounts for the eight states (MN, IL, NJ, WV, VA, PA, MD, and DE) must be completed to allow a robust comparative analysis of emergy indices. Our current research is focused on the development of methods to evaluate environmental liabilities, which are needed to complete the emergy balance sheet. Once this work is complete, we will have an accounting method to determine directly whether any human endeavor is sustainable

Section 5

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Section 6

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Petroleum Price
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Iron Ore Price
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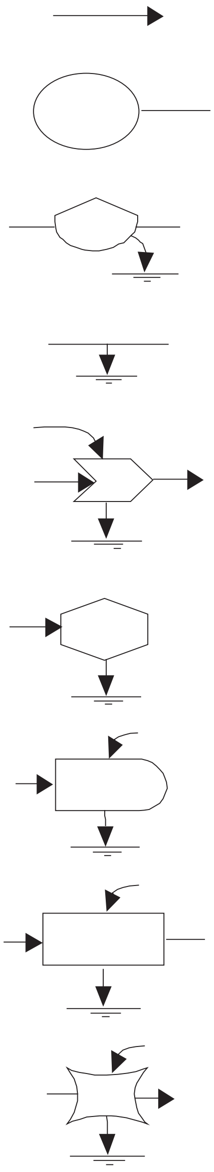
Appendix A

Primary Symbols of the Energy Systems Language



Energy circuit A pathway whose flow is proportional to the storage or source upstream.

Source A forcing function or outside source of energy delivering forces according to a program controlled from outside.

Tank A compartment or state variable within the system storing a quantity as the balance of inflows and outflows.

Heat sink Dispersion of potential energy into heat accompanies all real transformation processes and storages This energy is no longer usable by the system.

Interaction Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; a work gate.

Consumer An autocatalytic unit that transforms energy, stores it and feeds it back to improve inflow.

Producer Unit that collects and transforms low quality energy under the control of high quality flows.

Box Miscellaneous symbol to use for whatever unit or function is needed.

Switching Action A symbol that indicates one or more switching actions controlled by a logic program.

Figure A1. Primary symbols of the Energy Systems Language (modified from Odum 1994).

Appendix B

Sources, Adjustment, and Calculation of Transformities

B1. Information sources for the emergy per unit values used in this report. The note number links the emergy per unit values listed in this table to the values used in Tables 4-8. The emergy per unit values in Table B1.1 are given to three significant figures and shown for the 9.44, 9.26 and 15.83 E+24 sej/y baselines. Values are transformities with units of sej/J except where other units are noted. For example where emergy per unit mass is given a (g) for mass is noted next to the item and the units are sej/g. The emergy per unit of education level is sej per individual and the emergy to dollar ratio (sej/$) is used for services. Table B3.1 gives the factors used to convert one baseline to another. The 9.44 baseline (Odum 1996) was revised to the 9.26 baseline (Campbell & Odum, Appendix B in Campbell 1998, Campbell 2000a). The 9.44 values are reported, because many transformities in the older literature are given relative to this baseline. See http://www.epa.gov/aed/research/desupp3.html for additional information.

Table B1.1 The values and sources for transformities and specific emergies used in this report.

Note	Item	Source of transformity or specific emergy calculation	Emergy/unit 9.44	Emergy/unit 9.26	Emergy/unit 15.83
1	Incident solar radiation	(by definition)	1	1	1
2	Wind -	Odum (1996), p. 309	1496	1470	2.51E+03
3	Earth Cycle	Odum (1996), p. 309	34377	33700	5.76E+04
4	Rain, chemical potential	Odum (1996), Campbell (2003)	18200	18100	3.12E+04
5	Evapotranspiration,	Odum (1996), Campbell (2003)	18200	28100	4.80E+04
6	Rain, geo-potential, land	Odum (1996), p. 309	10488	10300	1.76E+04
7	Rain, geo-potential runoff	Odum (1996) (errata)	27764	27200	4.66E+04
8	Rivers, chemical	Odum (1996), Campbell (2003)	48459	50100	8.13E+04
9	Rivers, geo-potential	Odum (1996), p. 43	27764	27200	4.66E+04
10	Agricultural Products A weighted average of:	Brandt-Williams (2001) See B3 #7.		63000	
10	Hay (0.86)	See B3 #7.		40100	6.86E+4
10	Grains, fruits, tobacco	See B3 #7.		207600	3.55E+5
11	Livestock (poultry)	Odum et al. (1998)	7.36E+05	792000	1.23E+06
	Beef cattle	See B3 #7.		680000	1.14E+06
12	Fish Production -	Odum et al. (1998a)	2.0E+06	1960000	3.35E+06
13	Hydroelectricity -	Odum (1996), p. 186&305	1.23E+05	120300	2.06E+05
14	Net Timber Growth -	Tilley (1999), p.150	2.10E+04	20600	3.52E+04
15	Timber Harvest service	Tilley (1999)	7.00E+04	68700	1.17E+05
16	Ground water	Odum et al. (1998a)	1.62E+05	159000	2.72E+05
17	Coal	Odum (1996), p. 310	4.00E+04	39200	6.71E+04
19	Natural Gas	Odum (1996), p. 311	4.80E+04	47100	8.05E+04
21	Petroleum – Crude oil,	Odum (1996), p. 311	5.40E+04	53000	9.06E+04
23	Electricity -	Odum (1996),p.305& 311	173681	170400	2.91E+05
25	Clay Odum (1996) (g)	Odum (1996)	2E+09	1.96E+9	3.35E+09
26	Sand and Gravel (g)	(B3 # 5)	1.33E+9	1.31 E9	2.24E+09
27	Limestone (g)	Odum (1996)	1.0 E9	9.81 E8	1.68E+09
28	Sandstone (g)	Odum (1996)	1.0 E9	9.81 E8	1.68E+09
29	Erosion, topsoil	Odum (1996)	74000	72600	1.24E+05

Note	Item	Source of transformity or specific emergy calculation	Emergy/unit 9.44	Emergy/unit 9.26	Emergy/unit 15.83
31	Petroleum fuels	Odum (1996), p. 186	6.60E+04	64700	1.11E+05
33	Iron Ore	Odum (1996)	6.20E+07	60815800	1.04E+08
34	Aluminum ore, bauxite,	Odum (1996)	1.50E+07	14700000	2.52E+07
35	Services in goods ($)	1997 ($)		1.2 E+12	
36	Materials in Goods	(Table B2.1)			
44	Steel (g)	Brown & Buranakarn (2000)	3.45E+09	3380000000	5.79E+09
49	Standing Biomass	(B3 #3)		28200	4.82E+04
53	People (per individual)	Odum (1988, 1996)			
	Preschool (ind.)		3.40E+16	3.E+16	5.70E+16
	School (ind.)		9.40E+16	9.E+16	1.58E+17
	College Grad (ind.)		2.80E+17	3.E+17	4.70E+17
	Post-College (ind.)		1.31E+18	1.E+18	2.20E+18
	Elderly (65+) (ind.)	(B3 #4)		1.69E+17	2.89E+17
	Public Status (ind.)		3.93E+18	4.E+18	6.59E+18
	Legacy (ind.)		7.85E+18	8.E+18	1.32E+19
NA	Net Timber Prod.	Tilley (1999) p.150	1.10E+04	10800	1.84E+04
NA	Aluminum (g)	Brown & Buranakarn (2000)	1.25E+10	12300000000	2.10E+10

B2. Estimation of Transformities for the SCTG Commodity Classes. Transformities and specific emergies for each SCTG commodity classes were determined by averaging items within the class for which transformities were known. For classes where no transformities were available the transformity of the raw materials was used as a first order estimate. Transformities for the SCTG commodity class codes are given below as estimated from the transformities of the items listed. See Appendix D Table D1.1 for a definition of the items represented in the SCTG Class Code numbers. Emergy per unit is relative to the 9.26 baseline.

Table B2.1 Transformities and Specific Emergies for the SCTG Commodity Classes.

Class Code	Items in Class Average	Transformity sej/J	Sp. Emergy sej/g
1	Avg. poultry and cattle, Odum et al. (1987) Brandt-Williams (2001)	439,300	
2	Avg. wheat, grain corn, rice, oats, sorghum, Odum et al. (1987) Brandt-Williams (2001)	181,800	
3	Avg. soybeans, cotton, pecans, cabbages, oranges, etc. Odum et al. (1987) Brandt-Williams (2001)	233,400	
4	Forage Ulgiati et al. (1994) Cornstalks & wool Odum (1996), eggs Brandt-Williams (2001)	1.22 E6	
5	Meat (veal, mutton), shrimp, Odum (1996)	3.27 E6	
6	Use flour (wheat + energy to process)	181,800	
7	Sugar, palm oil and cacao from Odum et al. (1986b), milk Brandt-Williams (2001)	1.12 E6	
8	Use ethanol and avg. 10% alcohol by volume for beer and wine, Odum (1996)	58,900	
9	Use tobacco, Scatena et al. (2002)	650,000	
10	Use limestone Odum (1996)		9.81 E8
11	Use sand, this study		1.31 E9
12	Use granite rocks Odum (1996)		4.91 E8

Table B2.1 Transformities and Specific Emergies for the SCTG Commodity Classes continued.

Class Code	Items in Class Average	Transformity sej/J	Sp. Emergy sej/g
13	Use clay, Odum (1996)		1.96 E9
14	Use ore rocks, iron, alumina, copper, nickel, zinc Odum (1996)		2.71 E9
15	Use coal Odum (1996)	39,200	
17	Use crude oil, petroleum fuels Odum (1996)	64,700	
18	Use petroleum fuels Odum (1996)	64,700	
19	Use fuel oil Odum (1996)	64,700	
20	Use hydrated lime, caustic soda, diatomite, and sulfuric acid Odum et al. (2000b)		2.75 E9
21	Pharmaceutical and biological products (use chemicals as feedstock)		2.75 E9
22	Fertilizer from Brandt-Williams (2001) and Odum (1996)		2.99 E9
23	Insecticide (Brown and Arding 1991, paint and glue from Buranakarn (1998).		9.90 E9
24	(Plastic, tires, etc,) Odum et al. (1987)		2.71 E9
25	Use avg. softwood and hardwood logs Odum (1996)	19,600	
26	Use wood chips, lumber, particle board, plywood, Buranakarn (1998)		1.49 E9
27	(Use avg. wood pulp, paper, paper board), Tilley (1999)	139,800	
28	(Bags, packing, toilet paper, envelopes, wallpaper) Tilley (1999)	167,400	
29	Paper from Tilley (1999) Ink assumed similar to other chemical preparations		4.95 E9
30	Use avg. of textiles and leather Odum et al. (1987)	7.18 E6	
31	Use avg. ceramics, glass flat and float, brick, concrete, Buranakarn (1998)		3.09 E9
32	Avg. iron , steel, copper, aluminum Buranakarn (1998), Al 1/2 weight in avg		5.91 E9
33	Assume articles of metal have similar transformities to the unformed metal		5.91 E9
34	Machinery non electrical, Odum et. al. (1987)		7.76 E9
35	Assume the transformity for machinery applies Odum et. al. (1987)		7.76 E9
36	Assume the transformity for machinery applies Odum et. al. (1987)		7.76 E9
37	Assume the transformity for machinery applies Odum et. al. (1987)		7.76 E9
38	Assume the transformity for machinery applies Odum et. al. (1987)		7.76 E9
39	(Household furniture, lamps, mattresses) use hardwood, Buranakarn (1998)		2.89 E9
40	Miscellaneous manufactured goods		1.61 E9
41	Tire waste, wood waste, slag. Buranakarn (1998)		2.16 E9
43	Corn and steel for groceries and hardware		6.32 E9

B3. Calculation of New or Revised Transformities. In all cases transformity is determined by dividing the emergy (sej or sej/y) required for product or service by the energy (J or J/y) in the product or service. In this section, number simply refers to the new transformity calculations.

No.

1 **Calculation of Transformity for Forest Growth in West Virginia**

Evaportranspiration	3.67E+21 sej/y
Net Timber Growth (includes mortality)	2.10E+17 J/y
	17496 sej/J

2 **Calculation of Transformity for Forest Net Primary Production in West Virginia**

Evaportranspiration	3.67E+21 sej/y
Net Primary Production of Timber	3.09E+17 J/y
	11858 sej/J

3 **Calculation of Transformity for Forest Storage in West Virginia**

Evaportranspiration	3.67E+21 sej/y
Average age of a tree	80
Forest Storage	1.04E+19 J
Emergy to produce the forest	2.94E+23 sej
Transformity of biomass in 80 yr-old trees	28200 sej/J

4 **Calculation of the Transformity of the Elderly in West Virginia**

This estimate was based on the education level that elderly individuals in 1990 attained in 1930. The 1990 census showed that 8.75% of the population was 65-74 years old and that 6.24% of the population was 75 years and older.

In 1930, 86% of 14-15 year olds were in school. 20% of 18-20 year olds were also in school.
If the average age at graduation was 18 and the same pattern holds, around 20% of the high school age students graduated. In 1940, 4% of 21-41 year olds were enrolled in school. Assuming that these students graduated and that they indicate the average status of those born from 1915 to 1920 about 4% of the 1990 elderly aged 70 to 75 were college graduates.
The educational status of West Virginia in 1990 was estimated as follows: (1) 80% of 65 and older attended school but left between age 15 and age 18. (2) 20% were high school graduates and had some college and 4% were college graduates with some graduate work.

Education Status of Elderly individual	Individuals	Transformity sej/ind.
Total # 65 years or older in 1990	159518	
school (80%)	127615	9.2E+16
college (16%)	25523	2.7E+17
post-college (4%)	6381	1.3E+18
Emergy of all elderly individuals sej	2.69E+22	

Transformity of the elderly in West Virginia. **1.7 E+17 sej/ind.**

No.

5	**Transformity for Sand from Sandstone**	% SiO2
	Sandstone Composition from Rosler and Lange (1972) and Degens (1965). Assume complete weathering to quartz.	
	Arkose sandstone (California	61.6
	Glauconite sandstone (Switzerland)	78.34
	Sandstone	79.63
		73.19
	Assume loss of 25% of mass on weathering	0.75
	Transformity of sand stone	1.00E+09
	Transformity of sand from weathered sandstone based on mass concentration (1.0E9/0.75)	1.33E+09
	Transformity of sand on the 9.26 baseline (X 0.981)	**1.31E+09**

6 **Transformity for Electricity from Nuclear Power**

Odum (1996) p. 50, Uranium ore 1.88E9 sej/g = 1.84E+09 sej/g on the 9.26 baseline

Odum (1996) p. 154, From evaluation of Lapp (1991) use the figure, on p. 154.

Item	sej/y	Source
Emergy from the economy	9.128E+23	Lapp (1991)
Emergy from the environment	4.90E+22	Lapp (1991)
Emergy from uranium ore	1.43E+23	Calculated below
Total Emergy	1.11E+24	Sum previous 3
On 9.26 baseline	1.08E+24	X 0.981
Joules of electricity generated	2.09E+19	Lapp (1991)

Transformity of nuclear electricity	**5.19E+04**	**sej/J**

Parameters		
kWh per kg U fuel	50000	Data source *(39)*
Kwh per year generated	5.80E+12	Lapp (1991)
tons U fuel used	1.16E+05	calculated
tons ore used	7.63E+07	calculated
Specific emergy Uranium ore	1.88E+09	Odum (1996)

Average uranium produced in the U.S.	Mine n=10	Data Source *(40)*
million lbs U_3O_8	3.49	
1000 MT U	1.35	
	Concentrate n=10	Data Source *(40)*
million lbs U_3O_8	4.26	
1000 MT U	1.64	

No.			
6	fraction U in U_3O_8 from data above	0.850703226	calculated
	Stochiometry	0.847980998	calculated
	Oxygen, MW 16	128	
	Uranium, MW 238	714	
	For $30 per pound U	All sources (mining + leaching)	
	percent U_3O_8	0.17928	Data source *(41)*

7 **Revised Transformities for Agricultural Products.** Transformities for the agricultural products given in Brandt-Williams (2001) were recalculated with and without services using the 28100 sej/J as the transformity for evapotranspiration. The transformities without services included were used to determine the emergy of agricultural commodity flows. See http://www.epa.gov/aed/research/desupp3.html.

Table B3.1 The factors needed to convert one planetary baseline to another. All baselines are XE24 sej/y.

To convert baseline, X	To baseline, Y	Multiply by
9.44	9.26	0.981
9.44	15.83	1.677
9.26	9.44	1.019
9.26	15.83	1.710
15.83	9.26	0.585
15.83	9.44	0.596

Table B3.2 Estimation of the emergy to dollar ratio in the United States for 1997 and 2000

Data and methods in Odum (1996) pp. 312-315 were used to extrapolate the emergy/$ ratio.

Year	Fossil fuel use J/y	Transformity	Nuclear J/y	Transformity	Comment
1997	8.483E+19	53000	7.048E+18	157000	The transformity for electricity from coal was used to estimate the emergy contribution from nuclear electricity.
2000	8.848E+19	53000	8.451E+18	157000	

	Fossil fuel use E+24 sej/y	Nuclear E+24 sej/y	Renewable x E+24 sej/y	Other E+24 sej/y	Total Emergy Use E+24 sej/y	GNP $	Emergy/$* sej/$
1997	4.50	1.11	2.10	1.87	9.57	7.95E+12	1.20E+12
2000	4.69	1.33	2.10	1.87	9.99	9.31E+12	1.07E+12

* These emergy to money ratios are slightly different from the value used in Campbell et al. 2004a, because the earlier numbers were not corrected to the 9.26 baseline.

Appendix C

Calculation of Energy and Economic Values Used to Determine the 1997 Energy and Emergy Accounts for West Virginia

C1 Notes for Table 4 – Annual Renewable Resources and Production in 1997.
The numbers in parentheses and italics refer to data sources given above. Note that E+3= 10^3.

Note

0 **Area** 6.2362 E+10 m^2

Total land area of the state.

1 **Solar Energy**

Received	**3.074E+20 J/y**
Absorbed	**2.644E+20 J/y**

Solar energy received (J) = (avg. insolation)(area)(365 day/y)(4186 J/kcal)
Solar energy absorbed = (received) (1-albedo)
The average insolation and albedo were obtained from the NASA website (10) referenced in data sources. Eleven one-degree lat. by one-degree long. sectors covering the state were averaged.

	kW hm^{-2} y^{-1}	J m^{-2} y^{-1}	Joules y^{-1}
Solar energy received over the state	1369.414	4.93E+09	3.07436E+20
Solar energy absorbed by the state	1177.696	4.24E+09	2.64395E+20

2 **Kinetic Energy of Wind Used at the Surface** **1.074E+18 J/y**

Wind energy = (density)(drag coeff.)(geostrophic wind velocity)^3(area)(sec/year)

Calculated in Odum (1999) "Evaluating Landscape Use of Wind Kinetic Energy". The wind velocity used was a long-term average of four West Virginia stations up to 1993 (11). The common drag coefficient is about 1.0E-3 for ordinary winds of 10 m/s or less (Miller 1964) and 3.0E-3 over low mountains Garratt (1977). Winds over land are about 0.6 of the wind velocity that the pressure system would generate in the absence of friction (Reiter 1969).

air density	1.3 kgm^{-3}
wind velocity	6.98 mph
wind velocity (metric)	3.12 m s^{-1}
Geostrophic wind	5.2 m s^{-1}
drag coeff.	3.00E-03
area	6.2362 E+10 m^2
sec / year	3.14E+07

3 **Earth Cycle Energy** **1.39E+17 J/y**

Earth cycle energy (steady-state uplift balanced by erosion) =
(land area)(heat flow/area)
The heat flow per area is an average of nine wells throughout the state.
of West Virginia *(12)*.

Area	6.2362 E+10 m^2
Heat flow/area	70.56 mW m^{-2}
	2.23E+06 J m^{-2} y^{-1}

Note

4 **Rain Chemical Potential** **3.30E+17 J/y**

Chemical potential energy in rain =
(area)(rainfall)(density water)(Gibbs Free Energy water relative to seawater)
Average annual rainfall based on a one hundred year average from the National Climatic Data Center *(13)*.

Area	6.2362 E+10 m^2
Rainfall	1.1 m/y
Gibbs Energy	4.74 J/g
Density	1.00E+06 g m^{-3}

5 **Chemical Potential Energy of Evapotranspiration** **1.56E+17** **J/y**

Chemical potential energy in evapotranspiration =
(Area in land use)(Evapotranspiration)(density)(Gibbs Free Energy per gram)
Forest Transpiration estimated as 0.85 (Odum et al. (1998) of pan evaporation data measured from 1965 to 1990 at the US Forest Service Station at Fernow, WV (Adams et al. 1993). Direct measurements of evapotranspiration at Fernow in 1998 were used to check the long-term pan evaporation data. *(14)*. Evapotranspiration rates for crops and pasture from Arnold and Williams (1985).

Forest Area	49265769639 m^2
Forest Transpiration	5.59E-01 m/y
	1.00E+06 g m^{-3}
	4.74 J/g
	1.30E+17 J/y
Pasture area	2139634331 m^2
Evapotranspiration	0.7285 m/y
	7.39E+15 J/y
Crop area	2597767780 m^2
Evapotranspiration	0.694 m/y
	8.55E+15 J/y
Non crop area	2814248429 m^2
Evapotranspiration	0.7285 m/y
	9.72E+15 J/y
Total area	56817420179 m^2
Urban & barren area (by difference)	5544313542 m^2

6 **Geopotential Energy of Rain on Land** **3.66E+17 J/y**

Geo-potential energy of rain on land elevated above sea level= (area) (mean elevation) (rainfall) (density)(gravity). An area weighted average of rainfall and elevation by county was used to determine the geopotential energy of rain on land for a 30 year average rainfall in inches using GIS methods.

Table C1.1. Data used to determine the geopotential energy of rainfall.

County	Area m^2	Avg. elevation m	30 y avg. rainfall in.	geopot. energy
Hancock	228191120	322.427524	37.38536	6.85386E+14
Brooke	240176944	314.537809	39	7.34128E+14
Ohio	281945344	335.586703	39	9.19469E+14
Marshall	807178112	348.82437	41.29286	2.89704E+15
Preston	1686139648	630.98804	50.8542	1.34817E+16
Morgan	595436736	276.183843	37.02715	1.51725E+15
Mononga.	947073856	404.950628	43.57846	4.16448E+15
Wetzel	934991488	360.850872	45.24491	3.80371E+15
Mineral	853182720	397.950762	35.54701	3.0073E+15
Berkeley	833351552	199.736011	37.40184	1.55124E+15
Marion	806174464	376.575944	44.14345	3.33926E+15
Tyler	674734592	293.881773	43.70897	2.15963E+15
Hampshire	1669929728	377.768439	35.88709	5.64111E+15
Jefferson	548594112	160.223237	37.32662	8.17519E+14
Pleasants	348228768	273.18179	42.34601	1.00376E+15
Harrison	1078628224	366.759651	44.31864	4.3686E+15
Taylor	454673568	415.159562	45.41841	2.13624E+15
Doddridge	829267712	335.091023	45.02627	3.11764E+15
Wood	975464832	243.702585	40.0934	2.37491E+15
Ritchie	1174552960	297.039562	43.1418	3.75049E+15
Grant	1243197696	641.02717	38.34443	7.61415E+15
Barbour	887184064	521.134496	48.06692	5.53749E+15
Tucker	1090434304	857.48782	52.06758	1.2131E+16
Hardy	1513710208	537.310292	36.46919	7.39089E+15
Wirt	608199552	268.670655	42.90828	1.74707E+15
Lewis	1008180032	377.391402	46.69351	4.42679E+15
Randolph	2691785216	911.070648	53.8217	3.28891E+16
Upshur	918238400	560.858453	50.26036	6.44966E+15
Gilmer	878942080	318.033214	44.5842	3.10539E+15
Jackson	1220555904	252.196695	42.61932	3.26894E+15
Calhoun	725900992	307.80376	43.69557	2.43272E+15
Mason	1152245888	227.116475	41.11225	2.68082E+15
Pendleton	1807532672	794.104907	38.86252	1.38995E+16
Roane	1252050048	296.208663	43.66887	4.03547E+15

Table C1.1. Data used to determine the geopotential energy of rainfall continued.

County	Area m^2	Avg. elevation m	30y avg rainfall in.	geopot. energy
Braxton	1337042688	376.932653	47.07839	5.91199E+15
Pocahontas	2437553408	989.455485	49.93845	3.00115E+16
Webster	1439527296	753.490796	52.94361	1.43092E+16
Putnam	906781952	251.909579	41.98552	2.38974E+15
Clay	889922560	372.487511	46.3062	3.82477E+15
Kanawha	2357247232	325.598119	44.10259	8.43439E+15
Cabell	745557888	639.549	42.71017	5.07445E+15
Nicholas	1693563264	639.549502	49.14842	1.32644E+16
Wayne	1326469120	272.992341	43.54009	3.92862E+15
Lincoln	1136250368	290.620653	44.14746	3.63253E+15
Greenbrier	2651428096	808.361377	45.13994	2.41073E+16
Fayette	1730641664	612.812798	45.63472	1.20596E+16
Boone	1302429440	428.168433	46.35194	6.4408E+15
Logan	1179267712	435.418879	46.64979	5.96859E+15
Raleigh	1576129536	704.715715	43.79303	1.21203E+16
Mingo	1097541376	403.322368	45.97489	5.07104E+15
Summers	951547136	672.4003	38.51943	6.14102E+15
Wyoming	1299047680	596.885295	45.0688	8.70752E+15
Monroe	1225340928	708.407376	38.52779	8.3333E+15
Mercer	1088748160	768.072665	37.73166	7.8621E+15
McDowell	1384392576	599.940657	42.65404	8.82735E+15
Total	6.2723E+10			3.655E+17

Note

7 **Geopotential of runoff** **6.02 E+16 J/y**

Geopotential energy of runoff (physical energy of streams) =
(area)(mean elevation – (base elevation when > sea level)(runoff)(density)(gravity)
The annual runoff is a 30 year average. The elevation was also an average based on known elevations in the selected area *(15)*.

Watershed		
(Great Cacapon, WV)	Area	1.75E+09 m^2
	Elevation	609.6 m
(Potomac, Harper's Ferry)	Base elev.	73.2 m
	Runoff/yr	0.3175 m y^{-1}
	Density	1000 kg m^{-3}
	Gravity	9.81 m s^{-2}
	Energy	2.93E+15 J y^{-1}
(Bemis, WV)	Area	2.98E+08 m^2
	Elevation	1987 m
(Cheat R., Morgantown)	Base elev.	250.5 m
	Runoff/yr	1.069 m y^{-1}
	Density	1000 kg m^{-3}
	Gravity	9.81 m s^{-2}
	Energy	5.420E+15 J y^{-1}
(Little, WV)	Area	1.09E+07 m^2
	Elevation	1215 m
(Ohio R., Parkersburg)	Base elev.	171.3 m
	Runoff/yr	0.48006 m y^{-1}
	Density	1000 kg m^{-3}
	Gravity	9.81 m s^{-2}
	Energy	5.358E+13 J y^{-1}
(Buckeye, WV)	Area	1.40E+09 m^2
	Elevation	2303 m

Note			
	(Ohio R., Point Pleasants)	Base elev.	156.7 m
		Runoff/yr	0.5715 m y^{-1}
		Density	1000 kg m^{-3}
		Gravity	9.81 m s^{-2}
		Energy	1.683E+16 J y^{-1}
	(Clay, WV)	Area	2.57E+09 m^{2}
		Elevation	1821 m
	(Ohio R., Point Pleasants)	Base elev.	156.7 m
		Runoff/yr	0.68072 m y^{-1}
		Density	1000 kg m^{-3}
		Gravity	9.81 m s^{-2}
		Energy	2.855E+16 J y^{-1}
	(Julian, WV)	Area	8.24E+08 m^{2}
		Elevation	1667 m
	(Ohio R., Huntington)	Base elev.	149.1 m
		Runoff/yr	0.52578 m y^{-1}
		Density	1000 kg m^{-3}
		Gravity	9.81 m s^{-2}
		Energy	6.45E+15 J y^{-1}

Note

8	**River Chemical Potential**	Absorbed	**2.90E+14 J/y**
		Received	**9.06E+16 J/y**

River chemical potential energy received = (volume flow)(density)(Gibbs free energy relative to seawater)
River chemical potential energy absorbed = (volume flow)(density) (Gibbs free energy solutes at river entry – Gibbs free energy solutes at river egress)

The Ohio and New Rivers begin and end outside state boundaries delivering part of the chemical potential energy that they carry to the state.

Total Dissolved solids concentration from the USGS data *(16)*.
Gibbs Free energy, G = RT/w ln(C2/C1) = [(8.3143 J/mol/deg)(288 K)/(18 g/mol)] * ln [(1E6 - S)ppm)/965000], where R is the gas universal constant, T; the temperature in ^{0}K, and w: the molecular weight of the substance, S is the solute concentration in the river and seawater is assumed to contain 35 ^{o}/oo solutes.

Ohio River*	Vol. flow (Water Data - USGS)	2.948 E+10 m^3/yr
	Density	1000000 g/m^3
Solutes in (at Sewickley, PA)		211.96 ppm
	G. in	4.711 J/g
Solutes. out (Point Pleasant)		295.55
	G. out	4.700 J/g
	absorbed	3.279E+14 J/y
	received	1.389E+17 J/y

New River (Water Data - USGS)	Vol. flow	4.466 E+09 m^3/yr
	Density	1000000 g/m^3
Solutes in (Glen Lyn, VA)		84 ppm
	G. in	4.728 J/g
Solutes out (Point Pleasant)		295.5
	G. out	4.700 J/g
	absorbed	1.257E+14 J/y
	received	2.112E+16 J/y

*If the river flows along the border the state, the energy was distributed equally between the states on opposite sides of the river.

Note

9	**River Geopotential**	Absorbed	**2.06E+16 J/y**
		Received	**4.99E+16 J/y**

Geopotential energy received (relative to sea level) = (flow vol.)(density)(height at entry) (gravity).
Geopotential energy absorbed = (flow vol.)(density)(height entry - height egress)(gravity)
Ohio and New Rivers are the only rivers that begin and end outside of the state
Data on water flow and height of the gauge are from USGS Water Resources Data *(17).*

Ohio River*	Vol. Flow	2948 E+10 m^3/y
	(Water data - USGS)	
	Density	1000 kg/m^3
	Height In	207.26 m
	(Height at Sewickley, PA)	
	Height Out	155.45 m
	(Height at Point Pleasant)	
	Gravity	9.81 m/s^2
	Absorbed	1.499E+16 J/y
	Received	5.994E+16 J/y

New River	Vol. Flow	4.466 E+9 m^3/y
(Water Data - USGS)		
	Density	1000 kg/m^3
	Height In	454.23 m
(at Glen Lyn, VA)		
	Height Out	155.45 m
(at Point Pleasant)		
	Gravity	9.81 m/s^2
	Absorbed	1.309E+16 J/y
	Received	1.99E+16 J/y

*If the river borders the state half the calculated energy was used

Note

10 **Agricultural Products** **1.759E+16 J/y**

(amount sold)(energy/unit) Production data is from the West Virginia Agricultural Statistics Service Tables 42,43, and 37 in *(18)*. Most energy per unit values used were found in the USDA Nutrient Data Laboratory *(1)*.

Hay	Mass	8.0382E+11 g/y
	Energy/unit	18901 J/g
		1.519E+16 J/y
Oats		132,249 bushels/y
		14514.96 g/bushels
	Mass	1,919,588,945 g/y
	Energy/unit	16280 J/g
		3.125E+13 J/y
Wheat		421,453 bushels/y
		27215.54 g/bushel
	Mass	11,470,070,980 g/y
	Energy/unit	14230 J/g
		1.632E+14 J/y
Corn		3,651,139 bushels/y
		25401.17 g/bushels
	Mass	92,743,202,433 g/y
	Energy/unit	19736 J/g
		1.830E+15 J/y
Tobacco	Mass	2737090 lbs/y
		1,241,522,948 g/y
	Energy/unit	14651 J/g
		1.819E+13 J/y
Soybeans		482,228 bushels/y
		27215.54 g/bushels
	Mass	13,124,095,423 g/y
	Energy/unit	17,410 J/g
		2.285E+14 J/y
Apples	Mass	52,394,370,290 g/y
	Energy/unit *(1)*	2160 J/g
		1.142E+14 J/y
Peaches	Mass	4,615,592,663 g/y
	Energy/unit *(1)*	1650 J/g
		7.616E+12 J/y
Wool	Mass	80,796,141 g/y
	Energy/unit	20934 J/g
		1.691E+12 J/y

Note

11 **Livestock** **4.00E+15 J/y**
(annual production mass)(energy/mass)
The number sold is taken from the 1997 Census of Agriculture *(18)*.

Turkeys	# sold	4468456	
	wt	7257.5 g/animal	
	Energy /unit *(1)*	6690 J/g	All classes, meat and skin
		2.170E+14 J/y	
Cows	# sold	863647	
	wt	3.5E+05 g/animal	
	Energy /unit *(1)*	12180 J/g	Choice carcass
		3.7E+15 J/y	
Hog/Pig	# sold	24884	
	wt	9.00E+04 g/animal	
	Energy /unit *(1)*	15730 J/g	Fresh carcass
		3.52E+13 J/y	
Sheep/lamb	# sold	40709	
	wt	68038.9 g/animal	
	Energy /unit *(1)*	7406 J/g	Raw leg, shoulder, arm
		2.051E+13 J/y	
Horses	# sold	16787	
	wt	476271.99 g/animal	
	Energy /unit *(1)*	5560 J/g	
		4.445E+13 J/y	

12 **Fish Production** **7.22E+11 J/y**
(mass)(energy/mass)
Based on the 1998 trout sales of stocked fish reported by the US Department of Agriculture, 1998 Census of Aquaculture *(19)*.

Mass	369,000 lbs/y
	453.59 g/lb
Energy/mass	4311.58 J/g

13 **Hydroelectricity** **4.09E+15 J/y**
Energy Information Administration, Electricity Net Generation by Fuel in West Virginia, 1997 *(20)*.

Note

14 **Net Timber Growth** **2.10E+17 J/y**

Based on forest growth from 1975 to 1989, which are the last two inventories done for West Virginia by the U.S. Forest Service *(21)* (DiGiovanni 1990).

Forest Growth	491,132,000 ft^3
	1.39E+13 cm^3
green wt	1 g cm^{-3}
Forest growth	1.39E+13 g y^{-1}

15 **Timber Harvest** **2.29E+16 J/y**

Based on the forest statistics for West Virginia *(21)* DiGiovanni (1990).

Forest Harvest	462,542,000 board ft
	84,098,545 ft^3
	2.38E+12 cm^3
dry wt	0.5 g cm^{-3}
Forest mass	1.19E+12 g y^{-1}

16 **Groundwater Chemical Potential Energy** **9.49E+14 J/y**

(vol.)(density)(Gibbs free energy)

Based on the volume of ground water withdrawn in 1995 *(22)*.

G = RT/w ln(C2/C1) = [(8.3143 J/mol/deg)(288 K)/(18 g/mol)] * ln [(1E6 - S)ppm)/965000]

Volume used	2.02E+08 m^3 y^{-1}
(US Geological Survey on water use for state)	
Density	1000000 g m^{-3}
S	342 ppm
Gibbs free energy	4.69 J/g

C2 Notes for Table 5 – Annual Production and Use of Nonrenewable Resources in 1997.

17 **Coal Production** **4.64E+18 J/y**

Provided by the West Virginia Department of Energy *(23)*. Unit conversions may be found at (24).

Short tons/y	1.74E+08
g/short ton	9.07E+05
J/g	2.94E+04

18 **Coal Used in the State** **9.92E+17 J/y**

Provided by the West Virginia Department of Energy *(23)*.

Short tons/y	3.72E+07
g/short ton	9.07E+05
J/g	2.94E+04

Note

19 **Natural Gas Production** **1.89E+17 J/y**

Taken from the Energy Information Administration Natural Gas Summary Statistics for Natural Gas - West Virginia, *(25)*. The annual flows of natural gas are not exactly balanced because gas is supplied to and removed from underground storage. The flows balance over a longer averaging period.

Amount	1.72E+08 1000 ft^3
J/1000 ft^3	1.1E+09

20 **Natural Gas Used in the State** **1.75E+17 J/y**

Taken from the Energy Information Administration Natural Gas Summary Statistics for Natural Gas - West Virginia *(25)*.

Amount	1.59E+08	1000 ft^3
J/1000 ft3	1.1E+09	

21 **Petroleum Production** **9.2E+15 J/y**

From Utah's Department of Natural Resources
- Energy Office *(26)*

22 **Petroleum Used in the State** **2.3E+17 J/y**

(Energy Information Administration) From the State Energy Data Report of West Virginia 1960-1999. *(27)*

23 **Electricity Production** (without hydroelectricity) **3.26E+17 J/y**

Energy Information Administration *(28).*

Amount	9.042E+10 kWh

24 **Electricity Used in the State** **9.45E+16 J/y**

Energy Information Administration. From the State Energy Data Report of West Virginia 1960-1999. (27)

Amount	2.62E+10 kWh

Mineral Production

Taken from the 1997 and 1998 Mineral Industry Studies of West Virginia by the US Geological Survey and the West Virginia Geological and Economic Survey *(29)*.

Note			
25	**Clay**	151000 tons	**2.96E+20 sej/y**
	Emergy/Mass	1961864407 sej/g	(From Odum 1996)
26	**Sand and gravel**	1670000 tons	**3.34E+21 sej/y**
	Emergy/Mass	1.31E+09 sej/g	(Calculated in this study)

Note			
27	**Limestone**	12000000 tons	**1.18E+22 sej/y**
	Emergy/Mass	980932203 sej/g	(From Odum 1996)
28	**Sandstone**	856 tons	**8.40E+17 sej/y**
	Emergy/Mass	980932203 sej/g	(From Odum 1996)
29	**Soil Erosion**	Total	**5.03E+15 J/y**
		Agricultural lands	**3.99E+15 J/y**

(farmed area)(erosion rate)(organic fraction)(energy). The farmed area was taken from the 1997 census of Agriculture *(18)*. The organic fraction was taken from Odum (1996). Erosion rates for cropland and pasture from the USDA *(30)* and for forest from Patric et al. (1984).

Cultivated Crop	Area	641899.62	acres
	Erosion rate	4.3	ton/acre/y
	Erosion	27601685	ton/y
	Org. fraction	0.03	
		907185	g/ton
		22604.4	J/g
	Energy	1.69803E+15	J/y
Non-Cultivated	Farmed area	695391.26	acres
	Erosion rate	0.8	ton/acre/y
	Erosion	556313	ton/y
	Org. fraction	0.03	
		907184.74	g/ton
		22604.4	J/g
	Energy	3.42239E+14	J/y
Pastureland	Area	528696.4	acres
	Erosion rate	6	ton/acre/y
	Erosion	3172178	ton/y
	Org. fraction	0.03	
		907184.74	g/ton
		22604.4	J/g
	Energy	1.9515E+15	J/y
Forested Land	Area	12173404.9	acres
	Erosion rate	0.139	ton/acre/y
	Erosion	1692103	ton/y
	Organic fraction	0.03	
		907184.74	g/ton
		22604.4	J/g
	Energy	1.04097E+15	J/y

The erosion rate for the forested land was measured at Shavers Fork, WV.

C3. Notes for Table 6 - Imports to the West Virginia economy in 1997.

Note

30 **Coal** **2.32E+17 J/y**

Provided by the West Virginia Department of Energy *(23)*.

Short tons/y	8.70E+06
g/short ton	9.07E+05
J/g	2.94E+04

31 **Petroleum** **2.2E+17 J/y**

Value is the difference between the production and consumption within the state. Also estimated from the data in the 1997 Commodity Flow Survey *(2)*.

32 **Natural Gas (Received at state border)** **2.0E+18 J/y**

Taken from the Energy Information Administration data on Natural Gas *(5)*.

Most natural gas received passes through the state and thus it is not considered as an import. This value would not usually be shown in an emergy analysis, but it is given here to a give an idea of the emergy flows linking the nation.

Summary Statistics for Natural Gas - West Virginia,

Amount	1.79E+09 1000 ft^3
J/1000 ft^3	1.1E+09

33 **Iron Ore** **4.41E+13 J/y**

Data from Weirton Steel. Iron ore to satisfy 1997 production.

3.00E+06 tons/y
2.72E+12 g/y
16.2 J/g

34 **Bauxite imported (corrected number)** **4.4E+13 J/y**

Assume the ratio of bauxite ore to primary aluminum production is 4:1, alumina to production is 2:1(Century Aluminum, Ravenswood WV).

Aluminum production	1.7E+05 MT/y
bauxite	6.7E+05 MT/y
	6.7E+11 g/y
	6.5E+01 J/g

35 **Emergy of Services in Goods Imported** **2.99E+22 sej/y**

Data on shipments from the 1997 Commodity flow Survey, US. Census Bureau *(2)*.

	Units
Total in bound shipments	3.33E+10 $/y
Shipments of West Virginia origin	8.34E+09 $/y
Dollar value of imported goods	2.50E+10 $/y
Emergy to dollar ratio for the US in1997	1.20E+12 sej/$
Emergy in the services embodied in imported goods	2.99E+22 sej/y

36 **Emergy of Materials in Imported Goods (without fuels)** **9.48E+22 sej/y**

Data on material shipments into West Virginia by commodity class from the 1997 Commodity Flow Survey *(2)*, Additional State Data, Table 12. See Appendix B for the calculation of average transformities for the SCTG commodity classes. Appendix D gives details of the method of calculation used here.

Table C3.1 Emergy imported to West Virginia in material commodity flows.

SCTG Code	Commodity Class	J or g y^{-1}	Emergy per unit	Units	Emergy sej y^{-1}
1	Live animals and live fish	9.42E+13	4.39E+05	sej/J	4.14E+19
2	Cereal grains	1.10E+15	1.82E+05	sej/J	1.99E+20
3	Other agricultural product	2.09E+15	2.33E+05	sej/J	4.88E+20
4	Animal feed and products of animal origin	4.58E+15	1.22E+06	sej/J	5.58E+21
5	Meat, fish, seafood, and their preparations	1.91E+15	3.27E+06	sej/J	6.24E+21
6	Milled grain products and preparations	2.93E+15	1.82E+05	sej/J	5.33E+20
7	Other prepared foodstuffs and fats and oils	1.80E+16	1.12E+06	sej/J	2.01E+22
8	Alcoholic beverages	3.62E+14	5.89E+04	sej/J	2.13E+19
9	Tobacco products.	6.05E+14	6.50E+05	sej/J	3.93E+20
10	Monumental or building stone	3.23E+09	9.81E+08	sej/g	3.17E+18
11	Natural sands	3.69E+11	1.96E+09	sej/g	7.23E+20
12	Gravel and crushed stone	6.46E+12	4.91E+08	sej/g	3.17E+21
13	Nonmetallic minerals	7.30E+11	1.96E+09	sej/g	1.43E+21
14	Metallic ores and concentrates	3.04E+10	2.71E+09	sej/g	8.23E+19
15	Coal	2.25E+17	3.92E+04	sej/J	8.84E+21
17	Gasoline and aviation turbine fuel	1.07E+17	6.47E+04	sej/J	6.93E+21
18	Fuel oils	7.04E+16	6.47E+04	sej/J	4.56E+21
19	Coal and petroleum products	5.22E+16	6.47E+04	sej/J	3.38E+21
20	Basic chemicals	2.06E+12	2.75E+09	sej/g	5.65E+21
21	Pharmaceutical products	3.55E+10	2.75E+09	sej/g	9.77E+19
22	Fertilizers	1.94E+11	2.99E+09	sej/g	5.80E+20
23	Chemical products and preparations	1.89E+11	9.90E+09	sej/g	1.87E+21
24	Plastics and rubber	4.61E+11	2.71E+09	sej/g	1.25E+21
25	Logs and other wood in the rough	3.24E+15	1.96E+04	sej/J	6.35E+19
26	Wood products	5.67E+11	1.49E+09	sej/g	8.44E+20
27	Pulp, newsprint, paper, and paperboard	6.01E+15	1.40E+05	sej/J	8.40E+20
28	Paper or paperboard articles	3.18E+15	1.67E+05	sej/J	5.33E+20
29	Printed products	6.58E+10	4.95E+09	sej/g	3.26E+20
30	Textiles, leather, and articles	1.74E+15	7.18E+06	sej/J	1.25E+22
31	Nonmetallic mineral products	2.46E+12	3.09E+09	sej/g	7.60E+21
32	Base metal in primary or semi-finished form	1.30E+12	5.91E+09	sej/g	7.70E+21
33	Articles of base metal	4.42E+11	5.91E+09	sej/g	2.61E+21
34	Machinery	1.15E+11	7.76E+09	sej/g	8.89E+20
35	Electronic and other electrical equipment	1.57E+11	7.76E+09	sej/g	1.22E+21
36	Motorized and other vehicles	6.82E+11	7.76E+09	sej/g	5.29E+21
37	Transportation equipment	3.83E+10	7.76E+09	sej/g	2.97E+20
38	Precision instruments and apparatus	4.61E+09	7.76E+09	sej/g	3.58E+19
39	Furniture, mattresses, lamps, lighting	4.81E+10	2.89E+09	sej/g	1.39E+20
40	Miscellaneous manufactured products	2.66E+11	1.61E+09	sej/g	4.29E+20
41	Waste and scrap	6.24E+11	2.16E+09	sej/g	1.35E+21
43	Mixed freight	5.85E+11	6.32E+09	sej/g	3.70E+21
0	Commodity unknown	8.01E+10	?		?
	Total			sej/y	1.19E+23
	Total without fuels			sej/y	9.48E+22

37 **Services**

The emergy in imported and exported services was determined using a variation of the base-nonbase method from economic analysis. Data on employment and revenues by NAICS sector for West Virginia and for the United States as whole (31) were used to estimate services exported and imported from the state using a modification of the location quotient and assumption methods. The formulae in the text are evaluated using data from the tables below.

Table C3.2 Export and Import of Services Between West Virginia and the Nation

Economic Sectors

Parameters	Agricult.	Mining	Utilities	Construct.	Manufact.	Wholesale	Retail trade	Transport.	Informat.
US sector (N_i)	0.0249	0.0041	0.0057	0.0457	0.1362	0.0467	0.1128	0.0236	0.0247
State Sector (S_i)	0.0337	0.0349	0.0113	0.0457	0.1062	0.0347	0.1314	0.0212	0.0173
($S_i - N_i$)	0.0089	0.0308	0.0057	0.0000	-0.0300	-0.0120	0.0186	-0.0024	-0.0074
$/employee US	70034	341821	585899	151563	227502	700357	175889	108959	203255
$/emp. WV	19321	264699	420160	99198	251237	432277	156048	136256	149509
Location Quotient	1.36	8.50	2.00	1.00	0.78	0.74	1.16	0.90	0.70
(S_i) ÷ (N_i)	0.007	0.047	0.011	0.006	0.004	0.004	0.006	0.005	0.004
(S_t) ÷ (N_t)	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Basic jobs (B)	6075.20	21113.14	3882.36	-4.04	-20546.35	-8239.19	12742.19	-1620.47	-5088.21
Exp(+) or imp(-) $[*]	1.17E+08	5.59E+09	1.63E+09	-6.12E+05	-4.67E+09	-5.77E+09	1.99E+09	-1.77E+08	-1.03E+09
Services in Sector	none	part	part	imports	none	Local (no)	Local (no)	Local (no)	imports
Assumption	Base	Base	Base	nonbase	Base	nonbase	nonbase	nonbase	nonbase
$ value of goods	all goods	5.03E+09	1.38E+09		all goods				
Services exported[#]	0	5.61E+08	2.48E+08		0				

[*] Export is determined by multiplying basic jobs by the $/employee in the West Virginia sector. Potential import is determined by multiplying the basic job deficit by the $ per employee in the U.S. sector. Basic sectors can export.

[#] The export sectors summed here are only part service at this level of sector aggregation. Subtracting the dollar value of the goods exported in the sector from total estimated exports gives an estimate of the services exported. An alternative method (Table C3.3) considers higher resolution sector data where the export sectors evaluated are almost all service.

Economic Sectors continued:

Parameters	Finance& Insurance	RealEstate & Rental	Profession. Scientific	Managem.	Administ. Support	Education Services	HealthCare Social Ser.	Arts& Entertain.	Accomo. & Food
US sector (N_i)	0.0471	0.0137	0.0432	0.0211	0.0593	0.0026	0.1094	0.0128	0.0762
State Sector (S_i)	0.0308	0.0085	0.0240	0.0069	0.0313	0.0012	0.1397	0.0096	0.0752
($S_i - N_i$)	-0.0162	-0.0053	-0.0192	-0.0142	-0.0280	-0.0014	0.0303	-0.0032	-0.0010
$/employee US	376639	141515	111029	35328	40278	63659	65262	65956	37074
$/employee WV	205448	114420	75120	30082	37138	45921	60844	49389	31694
Location Quot.	0.66	0.62	0.56	0.33	0.53	0.47	1.28	0.75	0.99
(S_i) ÷ (N_i)	0.004	0.003	0.003	0.002	0.003	0.003	0.007	0.004	0.005
(S_t) ÷ (N_t)	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Basic jobs (B)	-11113.89	-3599.22	-13175.53	-9750.06	-19172.28	-931.94	20767.66	-2205.81	-718.72
Exp(+) imp(-) $[*]	-4.19E+09	-5.09E+08	-1.46E+09	-3.44E+08	-7.72E+08	-5.93E+07	1.26E+09	-1.45E+08	-2.66E+07
Services in Sector	Imports	Local (no)	Imports	Imports	Imports	Imports	Local (no)	Imports	Imports
Assumptions	nonbase	nonbase	nonbase	non base	nonbase	nonbase	nonbase	nonbase	Base

Sectors continued:

Parameters	Other Ser.	Auxillar.	Governm.
US sector (N_i)	0.0263	0.0064	0.1576
State Sector (S_i)	0.0264	0.0071	0.2028
(S_i - N_i)	0.0002	0.0007	0.0452
$/employee US	81659	14231	141198
$/employee WV	64655	1279	51394
Location Quot.	1.01	1.11	1.29
(S_i) ÷ (N_i)	0.006	0.006	0.007
(S_t) ÷ (N_t)	0.006	0.006	0.006
Basic jobs (B)	112.39	492.67	30980.10
Exp(+) imp(-) $*	7.27E+06	6.30E+05	1.59E+09
Services in Sector	Local (no)	Local (no)	Local (no)
Assumptions	nonbase	nonbase	Base

Table C3.3 Alternative Method for Determining Exported Service: Detailed Analysis of the Mining and Utilities sectors

Parameters	Drilling oil & gas wells	Support activities for oil & gas	Support activities for coal	Electric services
US sector (N_i)	0.0004	0.0009	0.0000	0.0020
State Sector (S_i)	0.0007	0.0014	0.0021	0.0032
(S_i - N_i)	0.0003	0.0006	0.0021	0.0012
$/employee US	138072	5451	22610483	465837
$/employee WV	77043	77270	135639	398779
Location Quot.	1.7317	1.6791	52.6411	1.6347
(S_i) ÷ (N_i)	0.0096	0.0093	0.2910	0.0090
(S_t) ÷ (N_t)	0.0055	0.0055	0.0055	0.0055
Basic jobs (B)	214	398	1425	850
Exp(+) imp(-) $*	1.65E+07	3.08E+07	1.93E+08	3.39E+08
Service exported ($)	5.80E+08			

Table C3.4 Determination of Imported and Exported Services

Potential for Importing ($)	8.01E+09	Multiply deficit employment times U.S. worker productivity in sectors assumed to be capable of importing services in Table C3. 2 and sum over the sectors.
Fraction of potential ($) imported	6.17E+09	We assume that states with average per capita income can import the service deficit and that states below US avg. per capita income can import a fraction of the deficit equal to average per capita income of the state /average U.S. per capita income. In 1997 this fraction was $19628/$25412 or 0.77 for West Virginia. Multiply potential imports by 0.77 to estimate imported services.
Emergy in exported services sej/y	7.0E+20	Multiply the basic employment in the detailed service sectors above by West Virginia worker productivity and sum. Multiply this dollar amount by the emergy to dollar ratio of the U.S. in 1997 to estimate the emergy exported
Emergy in imported services sej/y	7.4E+21	Multiply the imported services times the emergy to dollar ratio of the U.S. in 1997.

Table C3.5 West Virginia employment by sector and the dollars generated per employee, 1997.

Sectors NAICS	Number of Employees	Sales, Revenues, Shipments 1000 $	Dollars per Employee	Percent of total Employees
Agriculture	23135	447000	19321	0.0337
Mining	23927	6333463	264699	0.0349
Utilities	7767	3263383	420160	0.0113
Construction	31312	3106093	99198	0.0456
Manufacturing	72813	18293309	251237	0.1062
Wholesale trade	23805	10290356	432277	0.0347
Retail trade	90087	14057933	156048	0.1314
Transportation	14526	1979257	136256	0.0211
Information	11862	1773480	149509	0.0173
Finance & Insurance	21144	4344000	205448	0.0308
Real Estate & rental	5812	665011	114420	0.0084
Professional Scientific	16462	1236618	75119	0.0240
Management	4720	141988	30082	0.0068
Administrative support	21445	796429	37138	0.0312
Education services	843	38711	45920	0.0012
Health care & social services	95738	5825082	60844	0.1396
Arts& entertainment	6571	324534	49389	0.0095
Accommodation & food	51529	1633164	31694	0.0751
Other services	18113	1171099	64655	0.0264
Auxiliaries	4873	6235	1279	0.0071
Government	139000	7143800	51394	0.2027

Table C3.6 US employment and productivity by Industry sector, 1997

Sectors NAICS	Employees	Sales, receipts or Shipments $1000s	Dollars per Employee	Fraction of total Employees
Agriculture	3085992	216125000	70034	0.0248
Mining	509006	173988778	341821	0.0041
Utilities	702703	411713327	585899	0.0056
Construction	5664840	858581046	151563	0.0456
Manufacturing	16888016	3842061405	227502	0.1361
Wholesale trade	5796557	4059657778	700357	0.0467
Retail trade	13991103	2460886012	175889	0.1128
Transportation	2920777	318245044	108959	0.0235
Information	3066167	623213854	203255	0.0247
Finance & Insurance	5835214	2197771283	376639	0.0470
Real Estate & rental	1702420	240917556	141515	0.0137
Professional Scientific	5361210	595250649	111029	0.0432
Management	2617527	92473059	35328	0.0211
Administrative support	7347366	295936350	40278	0.0592
Education services	321073	20439028	63658	0.0025
Health care & social services	13561579	885054001	65262	0.1093

Table C3.6 US employment and productivity by Industry sector, 1997 continued.

Sectors NAICS	Employees	Sales, receipts or shipments $1000s	Dollars per Employee	Fraction of total Employees
Arts& entertainment	1587660	104715028	65955	0.01280
Accommodation & food	9451226	350399194	37074	0.0762
Other services	3256178	265897685	81659	0.0262
Auxiliaries	792370	11275968	14231	0.0063
Government	19540000	2759000000	141197	0.1575

Table C3.7 West Virginia detailed export sector employment and the dollars generated per employee.

Sectors NAICS	Number of Employees	Sales, Revenues, Shipments $1000s	Dollars per Employee	Percent of total WV Employees
Mining Services	2944	312178	106039	0.0042
Drilling oil&gas wells	506	38984	77043	0.0007
Support activities for oil & gas	985	76111	77270	0.0014
Support activities for coal	1453	197083	135638	0.0021
Electric services (electric power distribution)	2190	873325	398778	0.0031

Table C3.8 U.S. employment in detailed export sectors and the dollars generated per employee, 1997.

Sectors NAICS	Employees	Sales, receipts or Shipments $1000s	Dollars per Employee	Fraction of total US Employees
Mining Services	168806	19898686	117879	0.0013
Drilling oil&gas wells	52858	7298223	138072	0.0004
Support activities for oil & gas	106118	11501280	5451	0.0008
Support activities for coal	4993	578449	22610483	0.00004
Electric services (electric power distribution)	242347	112894143	465836	0.0019

Note

38 **Federal Government**

Personal Income Tax	2631000000	**$/y**	Data Source: *(33)*
Social Security Tax	2150000000	**$/y**	State of West Virginia (1999)
Business Taxes	2067026316	**$/y**	State of West Virginia (1999)
Total Tax (effective export)	**6.85E+09**	**$/y**	
Total Outlay to government and individuals	**1.04E+10**	**$/y**	From the U.S. Statistical Abstract for 1998 *(33)*
Net Gov. Funds spent in WV (1.04E+10)-(6.85E9)	**3.56E+09**	**$/y**	

C4. Notes for Table 7 - Exports from the West Virginia Economy in 1997.

39 **Coal** **3.82E+18 J/y**

Provided by the West Virginia Department of Energy *(23)*.

Short tons/yr	1.43E+08
g/short ton	9.07E+05
J/g	2.94E+04

40 **Natural Gas (Production Exports)** **6.65E+15 J/y**

Calculated from the Energy Information Administration Natural Gas Summary Statistics for Natural Gas-West Virginia *(25)*, Export is production – consumption.

Amount	6.05E+06	1000 ft^3
J/1000 ft3	1.1E+09	

41 **Natural Gas (Delivered at state border)** **2.08E+18 J/y**

Taken from the Energy Information Administration Natural Gas *(5)*. See Note 32 on the natural gas received at the state border. Summary Statistics for Natural Gas - West Virginia *(25)*.

Amount	1.89E+09	1000 ft^3
J/1000 ft3	1.1E+09	

42 **Electricity** **2.35E+17 J/y**

Energy Information Administration, *(28)*.
From the State Energy Data Report of West Virginia 1960-1999 *(27)*.
(Net generation)-(Consumption) = 6.53E+10 kW h

43 **Steel** **2.00E+12 g/y**

From Greg Warren at Weirton Steel in Wheeling, West Virginia

2.20E+06 ton/y

Note

44 **Services embodied in exported goods.**

Data on shipments from the 1997 Commodity Flow Survey *(2)*.
Data on electricity from EIA *(27)*. Electricity is not included in the CFS data.

		Units
<u>Total shipments to all destinations</u>	3.56E+10	\$/y
Shipments to West Virginia destinations	8.34E+9	\$/y
Dollar value of exported goods *(2)*	**2.72E+10**	\$/y
Emergy to dollar ration for the US in 1997	1.20E+12	sej/\$
Emergy exported in the services embodied in goods including fuels	**3.27E+22**	sej/y
Dollars paid for electricity @ .05 \$/KWh *(27)*	3.27E+09	\$
Emergy in services in Electricity exported	3.92E+21	sej/y
Total Emergy in services embodied in goods	**3.66E+22**	sej/y
Dollars paid for coal	3.92E+09	\$
Emergy in services in coal exported	4.70E+21	sej/y

45 **Material in exported goods**

Data on material shipments from West Virginia to all states by commodity is from The U.S. Census Bureau’s 1997 Commodity Flow Survey *(2)*, Additional State Data, Table 12. In some cases shipment weight from the commodity flow survey was converted to energy. See Appendix B for the calculation of average emergy per unit for the commodity classes.

Table C4.1 Emergy in the materials exported from West Virginia

SCTG Code	Commodity Class	J or g	Emergy per unit	Units	Emergy sej y^{-1}
1	Live animals and live fish	0	4.393E+05	sej/J	0
2	Cereal grains	0	1.818E+05	sej/J	0
3	Other agricultural product	0	2.334E+05	sej/J	0
4	Animal feed and products of animal origin	4.034E+14	1.217E+06	sej/J	4.471E+20
5	Meat, fish, seafood, and their preparations	1.720E+15	3.270E+06	sej/J	5.624E+21
6	Milled grain products and preparations	2.857E+13	1.818E+05	sej/J	5.195E+18
7	Other prepared foodstuffs & fats & oils	0	1.120E+06	sej/J	0
8	Alcoholic beverages	0	5.886E+04	sej/J	0
9	Tobacco products	1.595E+14	6.500E+05	sej/J	1.037E+20
10	Monumental or building stone	0	9.810E+08	sej/g	0
11	Natural sands	4.046E+11	1.962E+09	sej/g	3.969E+20
12	Gravel and crushed stone	1.660E+11	4.905E+08	sej/g	8.143E+19
13	Nonmetallic minerals	0	1.962E+09	sej/g	0
14	Metallic ores and concentrates	0	2.711E+09	sej/g	0
15	Coal	3.82E+18	3.924E+04	sej/J	1.500E+23
17	Gasoline and aviation turbine fuel	0	6.475E+04	sej/J	0
18	Fuel oils	4.021E+14	6.475E+04	sej/J	2.604E+19
19	Coal and petroleum products	1.26E+17	6.475E+04	sej/J	8.170E+21
20	Basic chemicals.	3.860E+12	2.750E+09	sej/g	1.061E+22
21	Pharmaceutical products.	0	2.750E+09	sej/g	0
22	Fertilizers	0	2.993E+09	sej/g	0

SCTG Code	Commodity Class	J or g	Emergy per unit	Units	Emergy sej y^{-1}
23	Chemical products and preparations	5.951E+11	9.902E+09	sej/g	5.893E+21
24	Plastics and rubbe	8.428E+11	2.709E+09	sej/g	2.283E+21
25	Logs and other wood in the rough.	2.9667E+16	1.962E+04	sej/J	5.821E+20
26	Wood products	2.562E+12	1.490E+09	sej/g	3.816E+21
27	Pulp, newsprint, paper, and paperboard.		1.398E+05	sej/J	0
28	Paper or paperboard articles.	5.752E+14	1.674E+05	sej/J	9.631E+19
29	Printed products.	0	4.951E+09	sej/g	0
30	Textiles, leather, and articles.	0	7.177E+06	sej/J	0
31	Nonmetallic mineral products.	1.224E+12	3.094E+09	sej/g	3.787E+21
32	Base metal in primary/semi-finished form	4.802E+12	5.906E+09	sej/g	2.836E+22
33	Articles of base metal	3.502E+11	5.906E+09	sej/g	2.068E+21
34	Machinery	1.261E+11	7.755E+09	sej/g	9.779E+20
35	Electronic and other electrical equipment	8.375E+10	7.755E+09	sej/g	6.495E+20
36	Motorized and other vehicles	4.107E+11	7.755E+09	sej/g	3.185E+21
37	Transportation equipment	0	7.755E+09	sej/g	0
38	Precision instruments and apparatus	0	7.755E+09	sej/g	0
39	Furniture, mattresses, lamps, lighting	2.994E+10	2.890E+09	sej/g	8.652E+19
40	Miscellaneous manufactured products	9126E+10	1.613E+09	sej/g	1.472E+20
41	Waste and scrap	0	2.161E+09	sej/g	0
43	Mixed freight	1.007E+11	6.316E+09	sej/g	2.064E+20
0	Commodity unknown	0	?	?	
	Natural Gas (joules)		4.80E+04	sej/J	3.19E+20
	Total				2.279E+23
	Total without fuels (15,17,18, natural gas)				**7.76E+22**
	Exported fuels				1.503E+23

46 **Services** See calculations at Note 37 above.

Dollar value of services exported	**5.796E+08**	$/y
Emergy in exported services	6.96E+20	sej/y

47 **People**

1997 Net Migration -9863 Individuals

Using the age percentages from the 1990 Census data

Number of individuals

	1990		1997
Preschool	21680	1.33%	-131
School	1166871	71.50%	-7052
College Grad	385026	23.59%	-2327
Post-College	56382	3.45%	-341
Total	1629959	99.87%	

The emergy per unit is expressed as sej/ind so the numbers are not put in energy terms.

48 **Tourism,** Estimate provided by the West Virginia Department of Transportation *(32).* **4.00E+09 $**

C5. Notes for Table 8 - Value of West Virginia Storages in 1997.

49 **Forest Storage** **1.04E+19 J**

Based on the forest statistics for West Virginia in the last inventory done by the U.S. Forest Service in 1989 Digiovanni (1990).

Forest Standing mass	7.60E+08 tons
	6.89E+14 g
	15069.6 J/g

50 **Available Coal Reserves** **1.42E+21 J**

Based on the estimated recoverable coal reserves in 1998 by the West Virginia Bureau of Commerce *(34)*.

mass	53326657317 tons
g/short ton	9.07E+05
J/g	2.94E+04 J/ton

51 **Available Petroleum Reserves** **1.19E+17 J**

Taken from *(35)* the Energy Information Administration Department of Energy.

Amount	2.10E+07 Barrels
	5.4E+06 Btu/barrel
	1.1E+14 Btu/yr

52 **Available Natural Gas Reserves** **3.13E+18 J**

Taken from *(5)* the Energy Information Administration Department of Energy (1997).

Amount	2.85E+09 1000 ft^3
J/1000 ft3	1.1E+09

53 **People**

Using the percentages from the 1990 Census data

1997 Population 1816000 people

Number of individuals

	1990	Fraction 1990	1997
Preschool	21680	0.0121	21952
School	1166871	0.6506	1181525
College Grad	379048	0.2113	383808
Post-College	50403	0.0281	51036
Elderly (65+)	157540	0.0878	159518
Public Status*	17935	0.0100	18160
Legacy#	792		792

*Public Status is estimated as one per cent of total population.

#All individuals listed in the index to *West Virginia: A History* by O.K. Rice are counted as part of West Virginia's legacy.

A few of those legacy individuals are:

Henry Davis - West Virginian senator and democratic candidate for the Vice Presidency of the United States in 1904 (lost to Roosevelt and Fairbanks)

Belle Boyd - confederate spy born in Martinsburg, WV

John Brown - known for his actions at Harper's Ferry
Pearl S. Buck - author who won the Nobel prize for literature in 1938, born in Hillsboro
Alexander Campbell, religious leader and educator. Bethany College and the Disciples of Christ.
Cornstalk - Shawnee Indian chief
John Davis - constitutional lawyer who argued 140 cases in the Supreme Court, most at the time also the unsuccessful democratic candidate for the US Presidency in 1924 (lost to Coolidge), born in Clarksburg.
Thomas J. "Stonewall" Jackson - confederate general, and exemplary leader.
John Kenna - West Virginian representative and senator, born in St. Albans.
Walter Reuther - president of the United Automobile Workers, born in Wheeling.
Francis Pierpont-governor of the "Restored Government of Virginia" during the Civil War born in Morgantown
Mary Harris "Mother" Jones - leader of strikers in the coal camps who fought for fair labor laws

C6. Notes for Table 9 – Summary Flows for West Virginia in 1997

54 Renewable emergy sources received (Table 4) are the chemical potential energy in rain, and the chemical potential energy in rivers. Renewable emergy sources absorbed by (used in) the system are the chemical potential energy of rain evapo-transpired, the geopotential of runoff doing work on the land, and the chemical potential and geopotential energy of the rivers used as the river flows through the state.

55 Nonrenewable sources (Table 5) include fuels and minerals coal, natural gas, petroleum, clay, sand and gravel, limestone and soil erosion where it exceeds soil building, *i.e.*, in agricultural areas.

56 Dispersed Rural Source (Table 5) is the soil erosion in agricultural areas. This category includes any renewable resource that is being used more rapidly then it is being replaced.

57 Mineral Production (Table 5) is the emergy in the mined tonnage of coal, natural gas, petroleum, clay, limestone, sandstone, sand and gravel.

58 Fuels exported without use are the quantities of coal and natural gas exported without first being used in a production process in the state. (coal production + import – use = 1522 E+20 sej/y) compared to the commodity flow survey number for coal (1497 E+20 sej/y). Use commodity flow survey number and add 3 E+20 sej/y natural gas exports.

59 Imported minerals and fuels are coal, petroleum, iron ore and bauxite (Table 6).

60 Minerals used (includes fuels): Add mineral production and mineral imports and subtract fuels exported without use.

61 In state minerals used: Subtract minerals exported without use from mineral production.

62 The material imported in goods was determined from the 1997 Commodity Flow Survey by summing the tonnage by commodity class from states with significant exports to West Virginia. (see note 36).

63 Dollars paid for imports is the sum of the dollar value of imported goods including fuels and minerals and all other goods and services.

64 The services in imported minerals including fuels are determined below.

Table C6.1 Services in Imported Minerals

	Amount	$/amount	$
Iron Ore (T)	3.0E+06	28.9	1.73E+08
Bauxite (T)	6.7E+05	27	1.8E+07
Coal (sT)	8.704E+06	26.64	2.32E+08
Petroleum (Btu)	2.09E+14		
Petroleum (Barrels)	3.89E+07		
Petroleum (Gal)	1.63E+09	0.799	1.31E+09
		Total	1.73E+09

The prices of these items can be found in the data sources given at *(36)*

65 Dollars paid for goods without fuels and minerals is the total dollar value of goods imported from the CFS ($2.5E+10) minus the dollar value in fuels and minerals calculated above.

66 Dollars paid for imported services as determined using the base-nonbase method (Table C3.3).

67 Federal transfer payments are the total outlay of funds by the Federal government (note 38).

68 Imported Services Total is the sum of the emergy in services associated with imported goods, fuels, and minerals, and pure services.

69 Imported Services in fuels and minerals is the emergy equivalent of the human service represented by the money paid for fuels and minerals. Dollars are converted to emergy using the 1997 emergy/$ ratio for the US.

70 Imported Services in Goods is the emergy equivalent of the money paid for goods minus that paid for fuels and minerals. (use 1.2E+12 sej/$).

71 Imported Service is the emergy equivalent of the money paid for services (note 37).

72 Emergy purchased by Federal dollars spent in the state. Use West Virginia emergy/$ ratio.

73 Exported Products is the emergy in the goods exported including electricity (Table 7).

74 Dollars Received for Exports is the sum of the payments for all exported goods and services

75 Dollars Received for Exported Goods other than fuels, is the dollar value of the exported goods ($2.72E+10) less fuels.

76 Dollars Received for fuels and electricity are determined in Table C6.2.

Table C6.2 Services in Exported Fuels and Electricity

	Amount	1997 prices $/amount	$
Coal (Short T)	1.43E+08	26.64	3.8E+09
Natural Gas (tcf)	6.09E+06	3.00	1.8E+07
		Total fuels	3.92E+09
Electricity (kWh)	6.53E+10	0.05 $/kWh	3.27E+09

77 Dollars Paid for Services as determined by the base-non-base method given in (Note 37).

78 Dollars spent by tourists in West Virginia from West Virginia Dept. Transportation *(32)*.

79 Federal Taxes Paid is the sum of personal income, social security, and business taxes (Note 38).

80 Total Exported Services is the sum of the emergy equivalents in human service in fuels, goods and services exported.

81 Exported Services in Fuels is the emergy equivalent of the human service in the dollars paid for fuels exported. Service is determined using the US emergy/$ ratio.

82 Exported Services in Goods is the emergy equivalent of the services embodied in all value added exported goods (goods and electricity minus fuels exported without use).

83 Exported service is the emergy equivalent of the dollar value of exported services (Note 37)**.**

84 Emergy Purchased by Tourists is the emergy purchased when tourists $ are spent in West Virginia, *i.e*., at West Virginia’s emergy to dollar ratio.

85 Emergy Purchases Forgone is the emergy equivalent of taxes paid to the Federal government. This number was determined using the West Virginia Emergy/$ ratio.

86 Gross State Product of the State of West Virginia in 1997.

87 Renewable Emergy received (note 54).

88 Renewable Emergy Absorbed (note 54).

89 In-State Nonrenewable Use is the sum of dispersed rural sources (N_0) and in-state mineral production (N_1).

C7. Notes for Table 10 - Calculation of Emergy Indices.

90 Imported Emergy is the sum of imported minerals (F), goods (G), and services (PI).

91 Total Emergy Inflow is the sum of renewable emergy received (R_R), and the emergy imported in the previous note.

92 The total emergy used in the state (U) is the sum of the renewable emergy absorbed (R_A), the emergy used form dispersed rural sources (N_0), fuels and minerals used (F_1), and the goods (G) and services (PI) imported.

93 Total exported emergy is the sum of the emergy in the materials of exported goods (B), the emergy of services associated with goods and with pure service (PE) and the emergy of fuels and minerals exported without use (N_2).

94 The emergy used from home sources is the sum of emergy from dispersed rural sources, in-state minerals and fuels used (F_2), and renewable emergy absorbed divided by total use (U).

95 Import minus export is the difference between imported emergy (note 90) and exported emergy (note 93).

96 Ratio of exports to imports is the quotient of the expression in note 93 divided by the expression in note 91.

97 Fraction of use that is locally renewable is the ratio of renewable emergy absorbed to total use.

98 Fraction of use that is purchased is the ratio of imported emergy (note 90) to total use (note 92).

99 Fraction of use in imported service is PI divided by U.

100 Fraction of use that is free is the sum of the renewable emergy absorbed and emergy from dispersed rural sources divided by total use.

101 Ratio of purchased to free is the quotient of the sum of imported fuels and minerals (F_1), imported goods (G) and imported services (PI) divided by the sum of the renewable emergy received (R_R) and the emergy from dispersed rural sources (N_0).

102 Environmental loading ratio is the quotient of the sum of the emergy from dispersed rural sources (N_0), imported fuels and minerals (F_1), imported goods (G) and imported services (PI) divided by the renewable emergy received (R_R).

103 Investment Ratio. There are several possible investment ratios (Odum 1996). This one compares imported emergy (note 90) to the emergy supplied form within the state. The emergy from within the state is the sum of the renewable emergy received (R_R), the emergy from dispersed rural sources (N_0), and the emergy from in-state fuels and minerals (F_2).

104 Emergy use per unit area (Empower density) is the total emergy use (U) divided by the area.

105 Use per person is the total emergy U divided by the population.

106 Renewable carrying capacity at the present standard of living is found by dividing the renewable emergy received by total use and then multiplying this fraction times the present population.

107 Developed carrying capacity at the present standard of living is approximately eight times the renewable carrying capacity.

108 West Virginia State Economic product (note 86).

109 Ratio of West Virginia emergy use to GSP. Divide U by X.

110 Ratio of U.S. Emergy use to GNP. See Appendix B3.2.

111 Ratio of emergy in electricity use to total use (El/U). See Table 5 for electricity use.

112 Ratio of electricity production to total use (Elp/U).). See Table 5 for electricity production.

113 Fuel use per person is the sum of coal, natural gas, and petroleum used in the state (Table 5, 620E+20 sej/y) divided by population.

114 Population of the State in 1997

115 Area of the State

Appendix D

Calculating Imports and Exports of Materials and Services

D1. Creating Export/Import Spreadsheets for Materials

The method used to determine the emergy exported from and imported to West Virginia was further developed in this study to take advantage of the extensive data on this subject provided by the U.S. Census Bureau's Commodity Flow Survey *(2)*, which is performed every five years. This innovation resulted in a marked improvement in the accuracy with which imports and to a lesser extent exports of a state's economy can be determined. Even though the CFS provides all the information needed to document exports and imports it is not tabulated in the form that we need and some of the information is hidden rather deeply in the data base. To make our method transparent and reproducible, we have described in detail the characteristics of the database, data sources and methods that we used to determine the emergy imported and exported from West Virginia. These methods should be applicable to the determination of imports and exports for any other state. To facilitate following the method described below the appropriate tables from the CFS should be accessed when needed. If the data tables or presentation of information change in the future these instructions will have to be altered.

Export Calculations

Determining material and energy flows for exports is straightforward with few extrapolations or assumptions needed, because the data are relatively complete as provided in the CFS. Data on dollar value and tonnage of export shipments between states by commodity class comes from the Commodity Flow Survey (CFS), Table 12 (Additional State Data). This data is also summarized in Tables 5, 7, and 8 in the CFS. The CFS uses several data codes when a numeric measurement is not given and these codes were handled in a consistent manner. For example, most states have an S or a D in one or more data fields for some commodity shipments. These letters indicate variable data (S) or a single source of information (D) that would risk disclosure. In the export calculation method, no estimate of exports was made for commodity classes with and S or D in both the $ value and tonnage columns for instate shipments. When this occurs there is often an S or a D in the "all destinations" category, as well. In this case there are too many unknowns to make an estimate. Materials moving in these classes were assumed to remain within the state or to constitute a negligible fraction of exports. Commodities with a dollar value but no information on tonnage were retained in the data because the tonnage could be reasonably estimated using the price per ton obtained from the dollar value and tonnage of the commodity going to all destinations.

Before transferring data from Table 12 to an interim spreadsheet, all dashes (indicating no data) were replaced with zeroes. If there was evidence that some flows were not actually zero, remained uncounted, or were different from the estimates provided, additional information was used when the emergy exported in each commodity class was determined. For example, coal exports also were determined using Energy Information Administration (EIA) Data. The Commodity Flow Survey provides a summary table (Table 7) of shipments to all states from the state of origin. Note that the top row in this table gives the total dollar value and tonnage of shipments from the state followed by a set of rows for dollar value and tonnage shipments to each state to which the state of origin is shipping. This includes a row for the state of origin itself, which will be referred to as instate shipments from now on.

An export table (see Table D 1.2) with 11 columns was made to use in determining the tonnage exported in various commodity classes. The commodity classes for SCTG, SIC, and NAICS industry classification codes and the approximate conversions used in this paper are shown in Table D1.1. The column headings for the export table are as follows (1) SCTG code, (2) Description of the class, (3) All Destinations Value($ mil), (4) All Destinations Tons(000), (5) $/Ton, (6) Instate Shipments ($ mil), (7) Instate Shipments Tons(000), (8) Known (directly measured) exports Tons(000), (9) Instate Tons (000) estimated using $/T, (10) Estimated exports tons (000), (11) Final Exports (estimated exports are adjusted to sum to the total missing tonnage). Table D 1.2 omits column 2, the verbal description of the SCTG code name, because of space considerations. The steps in estimating exports from a state, e.g., West Virginia, using the data in the spreadsheet columns described above are as follows:

Table D1.1. Approximate conversion between SCTG , SIC and NAICS industry classification codes developed for this study. These conversions are only approximate and better information might be developed of used if available.

Class	Combined Code	SCTG code	SIC code	NAICS Code
agricultural products, grain	A	2,3	1	111
livestock, seafood, animal products	B	1,4	2,9	112
logs, rough wood	C	25	8	113
metallic ores	D	14	10	2122
coal	E	15	12	2121
non-metallic minerals, gravel, stone, sand	F	11,12,13	14	2123
prepared food products, alcohol, tobacco	G	5,6,7,8,9	20,21	311,312
textiles, leather, apparel	H	30	22,23,31	313
lumber wood product	I	26	24	321
furniture, fixtures	J	39	25	337
paper products	K	27,28	26	322
printed products	L	29	27	323
chemicals	M	20,21,22,23	28	325
refined petroleum products	N	17,18,19	29	324
plastics and rubber	O	24	30	326
building materials, non-metallic	P	10,31	32	327,331
primary metal products, semi-finished	Q	32	33	331
fabricated metal products. Cans etc.	R	33	34	332
machinery (not electrical)	S	34	35	333
electrical equipment , precision instruments	T	35.38	36,38	334,335
transportation equipment	U	36,37	37	336
miscellaneous manufactured goods	V	40	39	339
scrap and waste	W	41	49 (?)	562 (?)
unknown, mixed or special classes	Y	43	92,98,99	99999

First, copy the Commodity Class code and description from the Commodity Flow Survey Table 12 (Additional Data) for the state, for which exports are to be calculated Columns (1 and 2). Remember in following the instructions below that column numbers refer to the 11 column headings recommended above. The 10 columns shown in Table D 1.2, which is missing column 2, have been numbered to match the verbal description.

1. Copy the $ value and tons moving from the state to all destinations for all commodities, Columns (3) and (4).
2. Calculate the $ per ton. Column (5)
3. Copy data ($ and Tonnage) for shipments of all commodities with final destination in the state of origin, e.g., from WV to WV, Columns (6) and (7).

4 Calculate known exports by subtracting instate shipments (column 7) from the shipments moving to all destinations (column 4) for all commodities for which tonnage has been measured, directly, Column (8).

5. Sum the tonnage of directly measured export shipments (Column 8) and subtract from the total tonnage moving to all destinations. The total tonnage is given at the top of the All Destinations column in Table D 1.2 and in CFS Table 12.
6. Calculate the tonnage of instate shipments for any commodity for which a $ value of instate shipments is given in column 6 by dividing by the $ per ton (column 5). Record in Column 9 the estimated instate shipments.

7. Estimate the tonnage exported in these commodity classes by subtracting the instate tonnage estimates (column 9) from tonnage moving to all destinations (column 4). Record these estimates in Column 10.
8. Sum the estimated export shipments (column 9) and divide into the difference between directly measured exports and total exports. If this ratio equals 1 combine directly measured and estimated exports in their respective commodity classes into a single column (11) and you are done. If greater or less than 1 multiply each estimated commodity by this ratio to adjust the flows so that directly measured and estimated exports will sum to the known tonnage of total exports shipped to all destinations. Record these numbers in Column (11), Final Adjusted Exports, and fill in column with the directly measured values from Column (8).

Table D1.2. Calculation of West Virginia Exports from the state to state commodity shipments found in the Commodity Flow Survey as Additional Data in Table 12.

SCTG Code	All DestinationsValue($ mil)	All Destinations Tons(000)	$/ton	Instate Value (mil $)	Instate Tons(000)	Measured Exports Tons(000)	Estimate Instate Tons(000)	Estimate State Exports	Final Adjusted Exports
Col. 1	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11
Total	35570	233760		8336	66249	167511			167511
1	-	-	0	-	-	0			0
2	-	-	0	-	-	0			0
3	S	S	356	S	S	S	S		0
4	129	467	276	87	438	29			29
5	609	259	2351	50	21	238			238
6	29	14	2071	20	11	3			3
7	223	S	843	S	S	S	S		0
8	365	351	1040	365	351	0			0
9	440	19	23158	177	7	12			12
10	S	S	94	S	S	S	S		0
11	32	793	40	4	347	446			446
12	53	5667	9	51	5484	183			183
13	S	S	29	S	S	S	S		0
14	S	S	689	S	S	S	S		0
15	4943	187835	26	1107	44488	143347			143347
17	393	S	272	S	S	S	S		0
18	227	964	235	224	954	10			10
19	532	3335	160	78	163	3172			3172
20	3918	5152	760	425	897	4255			4255
21	1996	S	32716	S	S	S	S		0
22	S	S	216	S	S	S	S		0
23	1512	946	1598	518	290	656			656
24	2582	1316	1962	485	387	929			929
25	370	5627	66	132	S	S	2007	3620	3406
26	900	3869	233	216	1045	2824			2824
27	69	108	639	S	S	S	S		0
28	123	87	1414	58	S	S	41	46	43
29	483	S	2499	S	S	S	S		0
30	S	S	9097	S	S	S	S		0

Table D1.2. Calculation of West Virginia Exports from the state to state commodity shipments found in the Commodity Flow Survey as Additional Data in Table 12 continued

SCTG Code	All Destinations Value($ mil)	All Destinations Tons(000)	$/ton	Instate Value (mil $)	Instate Tons (000)	Measured Exports Tons(000)	Estimate Instate Tons(000)	Estimate State Exports	Final Adjusted Exports
31	937	5007	187	263	3658	1349			1349
32	4158	6306	659	449	S	S	681	5625	5294
33	860	851	1011	525	465	386			386
34	2109	187	11278	483	48	139			139
35	1326	120	11050	242	S	S	22	98	92
36	2900	519	5588	212	S	S	38	481	453
37	320	S	10622	S	S	S	S		0
38	234	2	117000	S	-	S	S		0
39	159	45	3533	57	12	33			33
40	692	134	5164	140	S	S	27	107	101
41	S	S	148	S	S	S	S		0
43	794	425	1868	605	314	111			111
--	99	38	2605	S	S	S	S		0
Class Totals						158122		9977	167511
Difference (Total - Class Total from Column 7 in this Table.						9389			
Fraction (Difference/Class Total -Column 7/Column 9 this table)						0.941			

Transferring Export Data to the Emergy Evaluation Spreadsheet

Columns 1, 2 and 11 beginning with SCTG code 1, can now be transferred to the emergy export evaluation section. Do not include commodities with zero flow. These are only shown in Table D 1.2 as placeholders to present a complete listing of all commodity categories.

Import Calculations

Table 12 from the CFS web site, “Additional State Data”, used in the export calculation, has information on the exports by commodity class going from all the other states to the state of destination (West Virginia). Data from the other 49 states that might be exporting to the study state were combined to determine imports. Inbound shipments by state of origin to the state of destination are summarized in Table 8 of the CFS, but commodity classes are not shown. For states without a U.S. Customs port, state to state commodity shipments will capture almost everything entering the state. When one or more U.S. customs ports are located in a state the foreign imports entering the state need to be determined separately, regardless of whether they are immediately exported to another state. We assume that these imports bring some value to the state by simply passing through.

The inbound tonnage shipped in each commodity category was used to calculate the emergy imported in goods. The five steps used to estimate imported emergy to a state are as follows: (1) a quick tally of the total tonnage coming into the study state from other states was obtained by consulting Table 8 in the CFS report. The states that had a number entered in the percent of total inbound shipments column were identified. The total percentage of imports directly measured was determined by summing the percentages. We would like the total percent of tonnage from the states used to estimate imports to be at least 95% of the tonnage of total inbound shipments (2). Once the subset of states exporting to the study state was identified, missing values for the tonnage for specific commodities coming from each state were estimated. (3) If a dollar value of the inbound commodity shipments was known and tonnage was not listed, the tonnage was estimated based on the cost per ton as described above and shown in Table D 1.2. A large fraction of total inbound shipments from some states had missing values for both dollar value and tonnage (an S or D entered into the field). In this case, the missing data would have resulted in large errors in the estimate of total imports and thus the development of a method to handle this situation was warranted. The tonnage fields for inbound shipments from a state of origin to West Virginia containing and S or a D were handled by assuming that a state's exports to any other state would on average follow its overall export profile, *i.e.,* the fraction of total shipments accounted for by each commodity. Missing tonnage data was distributed among commodity classes by adjusting the overall export profile. The missing tonnage is equal to total shipments to West Virginia minus commodities with numeric entries for tonnage. This tonnage was distributed among the commodity classes of inbound shipments by adjusting the state's overall export profile so that the unknown inbound shipments made up 100% of the missing inbound tonnage. (4) The inbound tonnage in each commodity class for a state was transferred as a single column to a second worksheet with data from all of the identified import states. (5) Then each commodity class was summed across the rows for all states to create the column of data with imported tonnages in each commodity class for the emergy table.

1. The following steps describe the estimation of the unknown tonnage (S and D) as illustrated for Alabama's shipments to West Virginia shown in Table D 1.3. For all of the states importing to the study state, copy the total tonnage in each commodity class exported to all destinations and the tonnage exported to the state you are evaluating (columns 2 and 3 in Table D 1.3), onto a spreadsheet.
2. Calculate the price per ton for all inbound shipments by commodity class from any state exporting to the study state according to the instructions given above for exports.
3. Replace all dashes with a zero. Although Table D 1.3 only presents one state, the same procedure will be used for all states sending a significant quantity of imports to the study state.
4. Next, missing tonnage values are estimated for any commodity class that reported a dollar value of exports to the state but no tonnage. In some cases calculating the price per ton for the state of origin is not possible, but there is still a dollar value for exports. Prices per ton can be quite variable, but an estimate can be made by finding an adjacent state with similar export conditions for the product and substituting this price in the spread-sheet making a note on its origin. Fill in all tonnage movements possible using this method. Combine the tonnages estimated on the basis of average price with the tonnages that were directly measured. Sum this column and subtract from the total tonnage exported to get the tonnage that will be distributed using the export profile (see the number in italics at the top of column 4 in Table D 1.3). For example, the total export from Alabama to West Virginia is 318 thousand metric tons but the sum of all commodities determined directly and estimated based on dollar value only adds up to 27 thousand tons, the difference is then 291 thousand tons.
5. Create a fourth column for the state's export profile, which will be used to distribute the missing tonnage across the remaining commodities that had either an S or D in both the dollar value and tonnage fields. The export profile is the fraction of the total tonnage accounted for by each commodity as determined from the shipments to all destinations. Calculate the profile by dividing the tonnage for each commodity exported by the total tonnage exported for that state. Only those commodities that have an S or D in both dollar value and tonnage fields are recorded in column 4. Sum the fractions to determine the fraction of total tons accounted for by the commodities with missing data.

6. The next step is to adjust these fractions to represent the expected fractions of the missing tonnage imported to the state in each commodity class with missing data. Create a fifth column, the adjusted fraction of missing tonnage imported in each class, where each fraction of the tons in the export profile (individual values in column 4) will be divided by the fraction of the total tons that is missing (the sum of all fractions in column four). The sum of all values in column 5 should equal one, or 100%.
7. In the last column (column 6), copy over the reported and estimated data for tonnage for any commodity where it is available from column 3. For all of the missing commodities (those with and S or D in both the $ value and tonnage fields), multiply the total missing tonnage (at the top of Column 4) by the corresponding percentage (in Column 5) for each commodity class known to have a flow but for which tonnage is unknown, and transfer this number to the appropriate field in column 6. For example, if data is missing for textiles, multiply 291 thousand tons by the fraction of textiles or 0.0172, to get 5 thousand tons textiles imported. Sum this column to make sure it adds up to the total tonnage.
8. Transfer this tonnage data for each commodity to an import table creating a column for each state.
9. Sum across the states (rows) for each commodity to find the total tonnage imported in each commodity class and transfer this to the import section of the emergy evaluation.

<u>Custom’s Imports</u>

If the state has a Customs’ port, locate the appropriate data on the USITC data web site (37). The Customs’ site requires a password, but registration is free. To get the correct data report, a series of dialogue boxes must be completed. The choices that should be made are as follows:

- Dialogue 1 – U.S. General Imports; NAICS code; current US Trade
- Dialogue 2 – Customs value; 1997; All import commodities; All countries; All country sub-codes; create new district list
- Enter the name, select the districts, then highlight the name when you return to original page;
- In 1,000,000; annual; NAICS 3 digit; aggregate all countries together; aggregate import programs; display districts separately
- Dialogue 3 – Arrange in this order: District; NAICS 3
- Dialogue 4 – District; General customs value; Show all; Sort 1997; 5000 records; other display options are optional

Table D1.3: Example of estimating missing import data. Alabama to West Virginia

Description	Total Tons from Alabama (thousands)	Tons to WV (thousands)	Fraction of total tons for missing data	Fraction of missing tonnage to WV	Total Tons to WV (thousands)
All commodities	256234	318	*291*		
Live animals and live fish	125	-			0.0
Cereal grains	S	-			0.0
Other agricultural products	1682	-			0.0
Animal feed and products of animal origin	7194	S	0.028	0.059	17.2
Meat, fish, seafood, and their preparations	1836	S	0.007	0.015	4.4
Milled grain and bakery products	386	S	0.002	0.003	0.9
Other prepared foodstuffs and fats and oils	4408	S	0.017	0.036	10.5
Alcoholic beverages	482	-		0.000	0.0
Tobacco products	51	S	0.000	0.000	0.1
Monumental or building stone	S	-		0.000	0.0
Natural sands	S	-		0.000	0.0
Gravel and crushed stone	36211	-		0.000	0.0
Nonmetallic minerals	2905	S	0.011	0.024	6.9
Metallic ores and concentrates	S	-		0.000	0.0
Coal	30993	-		0.000	0.0
Gasoline and aviation turbine fuel	12659	-		0.000	0.0
Fuel oils	3605	-		0.000	0.0
Coal and petroleum products,	4671	S	0.018	0.038	11.1
Basic chemicals	7460	S	0.029	0.061	17.8
Pharmaceutical products	33	S	0.000	0.000	0.1
Fertilizers	2382	S	0.009	0.020	5.7
Chemical products and preparations	1271	S	0.005	0.010	3.0
Plastics and rubber	1585	S	0.006	0.013	3.8
Logs and other wood in the rough	40817	S	0.159	0.334	97.3
Wood products	12443	S	0.049	0.102	29.7
Pulp, newsprint, paper, and paperboard	8949	S	0.035	0.073	21.3
Paper or paperboard articles	977	-		0.000	0.0
Printed products	324	S	0.001	0.003	0.8
Textiles, leather, and articles of textiles or leather	2120	S	0.008	0.017	5.1
Nonmetallic mineral products	16613	S	0.065	0.136	39.6
Base metal in primary or semi finished forms and in finished basic shapes	11212	17			17.0
Articles of base metal	4208	S	0.016	0.034	10.0
Machinery	753	1		0.000	1.0
Electronic and other electrical equipment and components and office equipment	688	S	0.003	0.006	1.6
Motorized and other vehicles (including parts)	957	S	0.004	0.008	2.3
Transportation equipment	251	S	0.001	0.002	0.6
Precision instruments and apparatus	10	-		0.000	0.0
Furniture, mattresses and mattress supports, lamps, lighting fittings, and...	501	S	0.002	0.004	1.2
Miscellaneous manufactured products	2965	9			9.0
Waste and scrap	2130	-			0.0
Mixed freight	2000	-			0.0
Commodity unknown	S	-			
subtotals to check		27	0.476	1.000	318

D2. The Method for Calculating Services Imported and Exported

In this study, we adapted the base-nonbase method from economics to estimate the emergy of pure services imported and exported from West Virginia or any other state. This method was first used in an emergy analysis by Odum et al. (1998) and we used that work as a starting point. The theory and formulae for estimating services are given in the methods section above. There follows a detailed description of how we estimated exported and imported services. This material is given so that our method will be transparent and reproducible and therefore easier to refine and improve.

To determine exported and imported services, go to the NAICS economic sector data U.S. data *(31)* and then choose the state from the menu in the upper left-hand corner. You will also need agricultural and government data not given in *(31)*. Government expenditures by state are available in the U.S. Statistical Abstract for 1997 (also online). Agricultural data can be obtained from Economic Research Service, USDA Data- Farm and Farm-Related Employment *(38)*. These instructions create one large table comparing all of this data, but if smaller pieces are preferred, use a method that makes sense as long as the basic guidelines are preserved.

A) Using the list of non-farm industries given by NAICS two digit industry codes and recorded on the U.S. Census Bureau web site, there are 18 industry sectors (Table D 2.1), to which agriculture and government should be added. This table will be used to classify each sector as base or non-base. As mentioned in the services section of the main paper, base sectors are those that will have enough production to export, while non-base sectors are more likely to serve the local (state) economy. Agriculture, manufacturing, mining, and state and federal government are sectors that are often considered to be basic sectors. In the case of West Virginia, the utilities industry was added because it exports a large fraction of the electricity produced. Non-basic industries provide mostly local services such as support services and the retail industries like grocery stores, dry cleaners, drug stores etc. The data for each state should be examined and each of the 20 industry sectors designated as basic or non-basic industries using a set of initial assumptions. Since this method is only used to determine services imported and exported, each industry category must be further considered from this point of view. For example, in West Virginia exports from the manufacturing and agriculture sectors are almost entirely goods (this can be verified by examining the more detailed listing of higher digit industry sectors in the U.S. Census Bureau listing by NAICS code, see web site given above), the service component of which is determined below. In addition the mining and utilities sectors also are largely goods exporting sectors, however, each of these sectors has a service component. To accurately estimate the exports from these two sectors the detailed level of NAICS industry categories was used. This information is available at the same web address *(31)*. For example, within the mining sector there is a category for mining support activities. For West Virginia this category includes classes for drilling oil and gas wells, support activities for oil and gas operations and support activities for coal mining. All three of these are sources of potentially exportable services. The detailed code data should be used when it is needed for the particular economic situation in a given state. However, the two digit data can be used where the entire sector provides services for export or that might be imported. Table 1 gives a list of the 20 two digit industry categories and the assumptions that were made about them for West Virginia.

B) In the second table, the 20 sectors become the column headings and the data and calculations using this data are the rows. Table D 2.2 presents an abbreviated version of the total table (See Appendix C for the complete West Virginia table). The following steps are the same for calculating values for all columns, or sectors, and match the note numbers in Table D 2.2; however, you might want to complete rows 15 and 16 first. An explanation of the rows in Table D 2.2 follows:

1) U.S Paid employees. This number is from either the U.S. census table or one of the other two sites listed above for agriculture and government.

2) U.S. Sales, Receipts or Shipments ($1000). This number is from either the U.S. census table or one of the other two sites listed for agriculture and government.
3) U.S. Dollars per employee. Divide row 2 by row 1 and multiply by 1000.
4) U.S. Fraction of Total Employment. Divide row 1 by the value for line 15 (see note 15).
5) State Paid employees. This number is from either the WV census or from one of the other two sites listed above for agriculture and government.
6) State Sales, Receipts or Shipments ($1000).This number is from either the WV census or from one of the other two sites listed above for agriculture and government
7) State Dollars per employee. Divide row 6 by row 5 and multiply by 1000.
8) State Fraction of Total Employment. Divide row 5 by line 16 (see note 16).
9) Location Quotient. Divide row 8 by row 4. If this number is >1 the state is able to export a portion of this sector's productivity.
10) Sector ratio of regional to national employment. Divide row 5 by row 1.
11) Ratio of regional to national employment. Divide row 16 by row 15. This is a constant across all sectors and is an indication of the overall available workforce, regional to national.
12) Basic sector jobs. The number of basic jobs in a sector is found by subtracting the fraction of national employment in the region from the fraction of regional sector employment in the national sector, and then multiplying by national employment in the sector. Subtract row 11 from row 10 and multiply the difference by row 1. A positive number indicates an exporting sector and a negative number indicates a potential importing sector. However, the original assumptions about sector behavior will determine whether the potential for export or import is realized.
13) Exported goods and services are determined by multiplying the regional sector productivity per worker by the number of workers in the basic part of the sector. In other words, multiply row 12 by row 7 unless the initial assumptions about this sector make it a non-basic or non-exporting sector. Potential imports are determined by multiplying the national sector productivity per worker by the deficit number of workers for the sectors importing services. Multiply a negative value in Row 12 by the value in row 3.
14) Exports are corrected by subtracting the services in exported goods from the potential exports of a sector. For West Virginia this was done for two sectors – mining (see 14') and utilities.Other basic sectors were shown to either not export or to export only goods. The dollar value of goods exported from the sector must be subtracted form the total exports obtained in 13 to get an estimate of the services exported. We also estimated services exported by an alternative method. To use this method, step down one level of information into the structure of the exporting sector. Detailed information for these sectors is available (click on the arrow next to the sector in the main tables). Using this data, complete the same procedure used above for the pure service components of the sector to determine services exported directly. These estimates are totaled and constitute the estimate for exported services when summed over all basic sectors that export. To estimate the actual imports, we assumed that a fraction of the potential import (a negative amount on line 13) equal to the ratio of West Virginia's per capita income to national per capita income is actually imported into the state as explained above. Sum the positive values for exported services and the negative values for imported services, respectively. These totals are transferred to the import/export tables in the emergy evaluation for total services
15) For 1997 studies of U.S. states, the number provided here can be used for the national totals. It is the total employment for all sectors including agriculture and government.
16) West Virginia total employment in 1997 is the sum of employment in all sectors mentioned above.

Table D2.1. NAICS industry sectors and their assumed sector types for WV.

Industry	Sector Type	Notes
Agriculture	Basic-export	all goods
Mining	Basic-export	Support activities (only)
Utilities	Basic-export	Electric services (only)
Construction	Nonbasic	Local markets
Manufacturing	Basic	All goods
Wholesale trade	Nonbasic	Local markets
Retail trade	Nonbasic	Local markets (no export)
Transportation & Warehousing	Nonbasic	Local markets
Information	Nonbasic	Potentially imported
Finance &Insurance	Nonbasic	Potentially imported
Real estate & rental	Non-basic	Local markets
Professional, scientific services	Non-basic	Potentially imported
Management of companies	Non-basic	Potentially imported
Administrative support & waste management	Non-basic	Potentially imported
Educational services	Non-basic	Potentially imported
Health care and social assistance	Non-basic	Local markets (no export)
Arts, entertainment & recreation	Non-basic	Potentially imported
Accommodation and food service	Basic	not imported or exported
Other services (not public)	Nonbasic	Local markets
Auxiliaries	Non-basic	Local markets
Government	Basic	not exported

Table D2.2. Calculation of basic sector jobs and the estimated dollar values for exported and imported services.

Assumed sector behavior from Table 1		base	non-base
Note	Item	Mining	Constr
1	U.S Paid employees	509006	5664840
2	U.S. Sales, Receipts or Shipments ($1000)	173988778	858581046
3	U.S. Dollars per employee	341820.68	151563.16
4	U.S. Fraction of Total Employment	0.004094585	0.04556954
5	State Paid employees	23927	31312
6	State Sales, Receipts or Shipments ($1000)	6333463	3106093
7	State Dollars per employee	264699.42	99198.17
8	State Fraction of Total Employment	0.034013838	0.04451211
9	Location Quotient	8.31	0.98
10	Sector ratio of regional to national employment	0.05	0.01
11	National ratio of regional to national employment	0.01	0.01
12	Basic sector jobs	2.10E+04	-7.44E+02
13	Potential state services export/import	5.57E+09	-7.38E+07
14	State services export (+) or import (-)	1.02E+08	-3.69E+07
14'	Estimation of services actually exported using data for the entire mining sector. More detailed sector data that separates out service components may also be used		
	Total non-service mining receipts, WV	6,021,285,000	
	Total non-service mining employment, WV	20983	
	Total non-service mining employment, US	340200	
	Fraction total employment, WV	0.0298	
15	Total U.S. employment, all sectors plus agriculture and government	124311992	
16	Total WV employment, all sectors plus agriculture and government	703449	

Appendix E

West Virginia Emergy Accounts for 2000

Table E1. Renewable Resources and Production in the West Virginia Economy in 2000.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/ Unit sej/unit	Emergy E20 sej	2000 Emdollars E6 Em$
Renewable Resources within West Virginia						
1	Sun, incident	3.074 E+20	J	1	3	287
1	Sun, absorbed	2.644 E+20	J	1	3	247
2	Wind	1.074 E+17	J	1470	15.8	1475
3	Earth Cycle	1.388 E+17	J	33700	47	4372
4	Rain, chemical potential energy received	3.323 E+17	J	18100	60	5621
5	Evapotranspiration, chemical potential absorbed	1.561 E+17	J	28100	44	4099
6	Rain, geo-potential on land	3.655 E+17	J	10300	38	3518
7	Rain, geo-potential of runoff	6.024 E+16	J	27200	16	1531
8	Rivers, chemical potential energy received	9.056 E+16	J	50100	45	4240
8	Rivers, chemical potential energy absorbed	2.896 E+14	J	50100	0.15	14
9	Rivers, geo-potential energy received	4.987 E+16	J	27200	14	1268
9	Rivers, geo-potential energy absorbed	2.058 E+16	J	27200	5.6	523
Renewable Production within West Virginia						
10	Agricultural Products	5.340 E+16	J	50000	27	2495
11	Livestock					
	Beef	6.932 E+14	J	680000	4.7	441
	All other livestock	3.970 E+14	J	792000	3.1	294
12	Fish Production	7.099 E+11	J	1961800	0.14	1
13	Hydroelectricity	1.092 E+16	J	120300	13	1228
14	Net Timber Growth	2.096 E+17	J	20600	43	4035
15	Timber harvest	2.286 E+16	J	68700	16	1468
16	Ground water	9.493 E+14	J	159000	1.5	141

Table E2. Production and Use from Nonrenewable Sources within West Virginia in 2000.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/ Unit sej/unit	Emergy E20 sej	2000 Emdollars E6 Em$
Fuels and renewables used in a nonrenewable manner						
17	Coal Production	4.22 E+18	J	39200	1654	154,601
18	Coal Used in the State	1.03 E+18	J	39200	404	37,735
19	Natural Gas Production	2.91 E+17	J	47100	137	12,809
20	Natural Gas Used in the State	1.60 E+17	J	47100	75	4,043
21	Petroleum Production	9.50 E+15	J	53000	5	471
22	Petroleum Used in the State	2.26 E+17	J	64700	146	13,666
23	Electricity Production	3.40 E+17	J	170400	579	54,146
24	Electricity Used in the State	9.78 E+16	J	170400	167	15,607
25	Clay	3.40 E+05	T	1.9 E+15	6.5	604
26	Sand and Gravel	1.9 E+06	T	1.3 E+15	24.7	2,308
27	Limestone	1.2 E+07	T	9.8 E+14	118	10,991
28	Sandstone	1.0 E+06	T	9.8 E+14	10	916
29	Soil Erosion of agricultural areas	4.0 E+15	J	72600	3	271

Table E3. Imports to the West Virginia Economy in 2000.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/ Unit sej/unit	Emergy E20 sej	2000 Emdollars E6 Em$
30	Coal	2.30 E+17	J	39200	90	8,426
31	Petroleum	2.16 E+17	J	64700	140	13,060
32	Natural Gas (Received at state boarder)	1.58 E+18	J	47100	744	69,550
33	Iron Ore	4.41 E+13	J	6.08 E+07	27	2,506
34	Alumina/Bauxite	4.4 E+13	J	1.47 E+07	6	604
35	Services Embodied in the Goods	2.50 E+10	$	1.07 E+12	268	25,000
36	Material in the Goods	Various	J or g	Various	948	77,705
37	Services	6.2 E+09	$	1.07 E+12	663	62,000
38	Federal Government Outlays	1.07 E+10	$	5.79 E+12	620	57,900

Table E4. Exports from the West Virginia Economy in 2000.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/ Unit sej/unit	Emergy E20 sej	2000 Emdollars E6 Em$
39	Coal	3.19 E+18	J	39200	1250	116,867
40	Natural Gas (Production Exports)	1.20 E+17	J	47100	57	5,282
41	Natural Gas (Delivered at state border)	1.75 E+18	J	47100	824	77,032
42	Electricity	2.42 E+17	J	170400	412	38,539
43	Steel	2.00 E+12	g	3.38 E+09	68	6,317
44	Services Embodied in the Goods	2.72 E+10	$	1.07 E+12	291	27,200
45	Material in the Goods	Various	J or g	Various	776	72,523
46	Services	5.80 E+08	$	1.07 E+12	6	580
47	Migration (total)	2660	People	Various	4.2	344
	Preschool	876	People	3.3 E+16	0.3	24
	School	1188	People	9.2 E+16	1.1	90
	College Grad	479	People	2.7 E+17	1.29	106
	Post-College	117	People	1.3 E+18	1.5	125
48	Tourism	4.0 E+09	$	5.79 E+12	232	21,682
38	Federal Taxes Paid	6.1 E+09	$	5.79 E+12	353	32,990

Table E5. Value of West Virginia Storages in 2000.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E20 sej	2000 Emdollars E6 Em$
49	Forest	1.04 E+19	J	28200	2933	274,093
50	Coal	1.42 E+21	J	39200	556640	52,022,429
51	Petroleum	1.19 E+17	J	53000	63	5,894
52	Natural Gas	3.13 E+18	J	47100	1474	137,779
53	People 2000 population	1,808,344	Ind.		3908	365,394
	Preschool	21,635	Ind.	3.3 E+16	7	667
	School	1,164,463	Ind.	9.2 E+16	1071	100,122
	College Grad	384,232	Ind.	2.7 E+17	1037	96,955
	Post-College	56,266	Ind.	1.3 E+18	731	68,360
	Elderly (70+)	163,101	Ind.	1.7 E+17	277	25,913
	Public Status	18,568	Ind.	3.9 E+18	724	67,678
	Legacy	792	Ind.	7.7 E+18	61	5,699

Table E6. Summary of Flows for West Virginia in 2000.

Note	Letter in Fig. 2	Item	Emergy E20 sej	1997 Dollars $/yr	2000 Emdollars Em$/y
54	R_R	Renewable emergy received	105		9.82
54	R_A	Renewable emergy absorbed	66		6.17
55	N	Nonrenewable source flows	1958		182.99
56	N_0	Dispersed Rural Source	3		0.28
57	N_1	Mineral Production (fuels, etc.)	1955		182.71
58	N_2	Fuels Exported without Use	1312		122.62
59	F	Imported Minerals (fuels, etc.)	263		24.58
60	F_1	Minerals Used ($F+N_1-N_2$)	906		84.67
61	F_2	In State Minerals Used (N_1-N_2)	643		60.09
62	G	Imported Goods (materials)	948		88.60
63	I	Dollars Paid for all Imports		31.13	
64	I_1	Dollars Paid for Service in Fuels		1.72	
65	I_2	Dollars Paid for Service in Goods		23.24	
66	I_3	Dollars paid for Services		6.17	
67	I_6	Federal Transfer Payments		10.7	
68	PI	Imported Services Total	375		35.05
69	PI_1	Imported Services in Fuels	21		1.96
70	PI_2	Imported Services in Goods	280		26.17
71	PI_3	Imported Services	74		6.92
72	PI_4	Emergy purchased by Federal $	620		57.94
73	B	Exported Products (goods + elec.)	1188		111.03
74	E	Dollars Paid for Exports		31.08	
75	E_1	Dollars Paid Fuel Exported		3.92	
76	E_2	Dollars Paid for Goods		26.6	
77	E_3	Dollars Paid for Exported Services		0.58	
78	E_4	Dollars Spent by Tourist		4.0	
79	E_5	Federal Taxes Paid		6.1	
80	PE	Total Exported Services	379		35.42
81	PE_1	Exported Services in Fuels	48		4.49
82	PE_2	Exported Services in Goods	324		30.28
83	PE_3	Exported Services	7		0.65
84	PE_4	Emergy Purchased by Tourists	237		22.15
85	PE_5	Emergy Purchases Forgone	353		32.99
86	X	Gross State Product		39.7	

Table E7. West Virginia Emergy Indicators and Indices for 2000.

Item	Name of Index	Expression	Quantity	Units
87	Renewable Emergy Received	R_R	1.05E+22	sej y^{-1}
88	Renewable Emergy Used	R_A	6.6E+21	sej y^{-1}
89	In State Non-renewable	$N_0 + N_1$	1.958E+23	sej y^{-1}
90	Imported Emergy	F + G + PI	1.586E+23	sej y^{-1}
91	Total Emergy Inflows	$R_R + F + G + PI$	1.691E+23	sej y^{-1}
92	Total emergy used	$U = R_A+N_0+F_1+G+PI$	2.298E+23	sej y^{-1}
93	Total exported emergy	$B+ PE +N_2$	2.879E+23	sej y^{-1}
94	Emergy used from home sources	$(N_0+F_2+ R_A)/U$	0.31	
95	Imports-Exports	$(F+G+PI)-(B+PE+N_2)$	-1.29E+23	sej y^{-1}
96	Ratio of export to imports	$(B+PE+N_2)/(F+G+PI)$	1.81	
97	Fraction use, locally renewable	R_A /U	0.030	
98	Fraction of use purchased import	(F + G + PI)/U	0.68	
99	Fraction used, imported service	PI/U	0.15	
100	Fraction of use that is free	$(R_A+N0)/U$	0.029	
101	Ratio of purchased to free	$(F_1+G+PI)/(R_R+N0)$	20.6	
102	Environmental Loading Ratio	$(F_1+N0+G+PI)/(R_R)$	21.3	
103	Investment Ratio	$(F+G+PI)/(R_R+N_0+F_2)$	2.11	
104	Use per unit area	U/Area	3.7E+12	sej m^{-2}
105	Use per person	U/Population	1.27E+17	sej/ind
106	Renewable Carrying Capacity at present standard of Living	(R_R /U)* (Population)	82,702	people
107	Developed Carrying Capacity at same living standard	8(R/U)(Population)	661,619	people
108	WV State Econ. Product	GSP	3.97E+10	$/yr
109	Ratio of WV emergy use to GSP	U/GSP	5.79E+12	sej/$
110	Ratio of U.S. emergy use to GNP in 2000	U/GNP	1.07E+12	sej/$
111	Ratio of Electricity/Emergy Use	El/U	0.073	
112	Ratio Elec. Prod./Emergy Use	Elp/U	0.25	
113	Emergy of Fuel Use per Person	Fuel use/Population	3.4E+16	sej/ind
114	Population		1.811E+6	people
115	Area		6.236E+10	m^2