Ecology and Economy: "Emergy" Analysis and Public Policy in Texas

Lyndon B. Johnson School of Public Affairs
The University of Texas at Austin
Policy Research Project Report

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FOREWORD

The Lyndon B. Johnson School of Public Affairs of The University of Texas at Austin has established interdisciplinary research on public policy problems as the core of its educational program. A major part of this program is the nine-month policy research project, in the course of which two or three faculty members from different disciplines direct the research of ten to twenty graduate students from diverse backgrounds on a policy issue of concern to an agency of government. This "client orientation" brings the students face to face with administrators, legislators, and other officials active in the policy process, and demonstrates that research in a policy environment demands special talents. It also illuminates the occasional difficulties of relating research findings to the world of political realities.

This report, which examines and evaluates the relationships of natural and environmental resources to the Texas economy, is the product of a policy research project conducted at the LBJ School in the academic year 1985-86. The report utilizes an innovative method of measuring the value of an input on a common basis, termed "emergy", to evaluate contributions of resources and services to the gross state product. Policy alternatives for the Texas economy are recommended based upon the best utilization of available resources. Partial support for the project, including publication of the report, was provided by the Texas Department of Agriculture.

The curriculum of the LBJ School is intended not only to develop effective public servants but also to produce research that will enlighten and inform those already engaged in the policy process. The project that resulted in this report has help to accomplish the first task; it is our hope and expectation that the report itself will contribute to the second. Finally, it should be noted that neither the LBJ School, the University of Texas at Austin, the University of Florida, nor the Texas Department of Agriculture necessarily endorses all of the views or findings of this study.

Max Sherman
Dean

PREFACE

This report was prepared by Howard T. Odum and Elisabeth C. Odum with the advice of Robert King from papers generated in a Policy Research Project at the Lyndon Baines Johnson School of Public Affairs of The University of Texas at Austin, 1985-1986. Final preparation was assisted by Stephen Tennenbaum, Barbara Henry, and Judith Clark, Department of Agriculture and Joan Breeze and Steve Roguski, Center for Wetlands, University of Florida, Gainesville.

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EXECUTIVE SUMMARY

The objective of this project is to examine and evaluate the relationship of natural and environmental resources to the Texas economy and some of its sectors. Subsystems studied included oil and gas, lignite, agriculture, water resources, wetland wastewater recycling, exchanges with Mexico, highway transportation, and marine resources. Environmental systems diagrams of Texas, the nation, and some critical sectors of the economy were made to obtain a perspective on the Texas economy and examine its resource bases.

A new measure, <u>emergy</u>, spelled with an <u>m</u>, which represents the value of an input on a common basis, was used to evaluate contributions of resources and services to the gross state product. Emergy analyses were made using data from 1983. Policy alternatives with high emergy contributions were recommended on the assumption that they are likely to be more successful because they contribute more than other options to the total economy of humanity and nature.

PREDICTIONS OF FUTURE ECONOMIC TRENDS

Microcomputer simulation models using the calculated emergy values of resource reserves, economic assets, and their expected rate of use, predict a turndown for the total economy in the next decade. In the United States and in Texas, declining resources increasingly will cause a leveling of growth followed by a gradual decline. Possible measures for making a declining economy prosperous include across-the-board salary reductions, which tend to cut back on luxury consumption without causing unemployment with its increased welfare costs and crime and elimination of wasteful excesses in transportation and resource use, which makes products more competitive.

FUEL RESOURCES

The 28 percent of the oil and gas pumped in Texas that was exported from the state stimulates the economies of recipient states and countries from 6 to 12 times the dollar price received by Texas producers. If more of the gas and oil produced in Texas could be used within the state, the Texas economy would be stimulated instead of the economies of the other states and countries.

Emergy analysis of the Big Brown power plant at Fairfield shows lignite coal with a net emergy yield ratio of 6.9 and its electricity output a net emergy yield ratio of 2.2. The net emergy yield ratio is a measure of how much emergy is yielded from a process compared to all the services and other inputs from the economy necessary to produce it. As the ratio increases, the amount of economic activity supported by the product increases. Big Brown has been competitive with available oil and gas, except during the temporary low fuel prices of 1986. The emergy costs of reclamation at these sites make a very small increase in the cost of the electricity produced and a very large contribution to the environmental value of the restored land.

AGRICULTURE

Agriculture directly contributes 9.5 percent of the total emergy of the state economy and is the basis for an additional 18 percent for a total of 27 percent. Agriculture generates 7 times more economic activity than the dollar value of its market sales (3.8 percent of gross state product). Declining availability of fuel will increase these percentages.

Contrary to traditional ideas, using diversified farm products within the state stimulates the economy; outside sale of raw commodities as cash crops hurts the economy. Agricultural products carry the economic benefits of environmental contributions, such as rain and soil, which are not recognized in sale prices. These values stimulate the economy of the user. Selling grain and livestock instead of using them at home is an economic giveaway. Also contrary to common belief, a weak dollar does not favor the economy, because overseas buyers can purchase more real wealth (such as agricultural products) for less money. With a weak dollar the home economy gets less real wealth in purchasing fuels.

A competitive position in agriculture now requires reducing the intensity of farming (using less fuels, chemicals and equipment) and optimizing (rather than maximizing) unit productivity at lower cost. A higher ratio of land, environmental work, and labor will be used, with less purchased inputs of machinery, fertilizer, and pesticide. One example of how to obtain more labor without increased costs would be to absorb unemployed city youth as well as young immigrants on farms by making farm land available for housing and for garden plots. Reducing minimum wages for youth and the elderly decreases unemployment, makes products more competitive, and provides apprentice training for increasing numbers in farming communities. Large farms differ from small farms in Texas by having higher intensity and costs. Small farms are closer to the pattern that will become more economical.

Six-foot farm windmills, pumping water and driven by 17 mile-per-hour wind velocity 12 hours per day are not a net emergy yielder, which means that they take more from the economy than they yield. However, windmills that pump groundwater have a relatively high contribution to the economy per unit cost. The cost of using electricity for pumping water is comparable to the cost of windmill pumping, but the windmills use only one-third as much of the economy's resources. These windmills contribute to overall energy conservation. Average wind velocity in Texas is 9.7 miles per hour.

WATER

Water is a net emergy contributor to the economy. Much more value is delivered to the economy through irrigation than is paid for the pumping of the water. Emergy analysis shows that agricultural use of water contributes more to the economy than urban use, even though residential water costs more. The high emergy value of water justifies water conservation measures. Fresh water yields more energy (and emergy) in desert areas than humid areas.

After they are no longer needed for fuels, the network of oil and gas pipelines in coastal Texas, with suitable modification, could move water from east Texas to south Texas, since little uphill pumping would be required.

WASTE DISPOSAL

Sanitary landfill disposal of solid waste diverts emergy from the economy by removing land from production, threatens water quality, wastes critical materials, and requires unnecessary fuel use. Alternatives that involve more reuse, recycling of materials to environmental ecosystems, and fewer collections save economic value. Dispersal of some solids over natural landscapes to become part of the normal ecological and geological cycles may be preferable to concentrated landfills and other storages that become toxic liabilities.

At Port Aransas, Texas, secondary treated wastewaters contribute to the economy by developing freshwater and saltwater marshes. Development of these marshes reduces treatment costs, provides wildlife refuge, saves fresh waters by reducing saltwater intrusion, and reduces taxes. This system may be a suitable prototype for much of Texas. The economic contribution of the marsh productivity is over $200 thousand per year.

MARINE RESOURCES

The marine resources of the estuaries and the Gulf of Mexico shelf include tides, waves, fisheries, metabolic means to treat wastes, and cheap transportation systems. They contribute $3.5 billion of macroeconomic value to the economy and are the means for attracting an additional $24.5 billion of economic activity to the coastal counties. These resources will give the coastal counties an increasing edge in economic competition as fuel availabilities decline.

The bays are used for considerable waste treatment (contribution estimated at $1.8 billion per year), but if these estuaries become overloaded or if their biological functions otherwise are impaired, higher taxes to pay for treatment plants will result. Measures that would reduce bay processing capacity include diverting fresh waters, blocking off circulation, or adding turbidity through dredging.

TRANSPORTATION

Highways are now so numerous that maintenance does not keep up with depreciation. Because of the indirect incorporation of the emergy values of fuels, asphalt, and cement, the highways and their vehicles have much higher emergy content than is inferred from the dollars spent. Because larger vehicles are used than needed, the number of roads and their depreciation are higher than necessary. Large savings are possible by reducing the number of roads and the size of vehicles, and by substituting communication for transportation.

TRADE

The emergy use per dollar in Texas is greater than the average in other states. As a result, in trade, Texas gives more resources for the dollar to other states than it receives from them. In exporting oil and grain, Texas has operated like a colonial dependent, helping other states and nations more than it receives in payment. The payback in the macroeconomic value of federal transfer funds, military bases, and NASA installations is much less than the value exported in raw products.

RELATIONS WITH MEXICO

In trade between Texas and Mexico in 1983, an international dollar in Mexico had a slightly higher emergy (buying power). This gave Texas a net benefit when trade was arranged on an international dollar exchange basis. The emergy use per person is about 9 times more in Texas than in Mexico. This index of standard of living helps explain the high level of immigration into Texas. Preliminary estimates of total emergy exchange across the border suggest that Texas receives twice as much value as it returns. Balanced emergy exchange may produce long-range stability, more equity, and less immigration. Possible suggestions for ways to work toward a more equal balance include immigration, dual plants, Texas investment in Mexico, increasing Mexican use of its own fuels, and flow of knowledge.

DEFENSE

Because of the direct resource inputs to defense, including fuels, steel, aluminum, critical metals, and education, defense emergy uses are 8 percent of the total resource use of the U.S. whereas on a dollar basis 6 percent goes for defense. Macroeconomic value used by uniformed personnel is 11 percent of the total defense; civilian service, 17 percent; fuel, 13 percent; and equipment contractors, 32 percent.

The net emergy input to the U.S. economy from trade with countries that are under the U.S. defense umbrella is 3 times that of the total defense system and 9 times higher than the overseas emergy use in maintaining that umbrella.

Although transfer payments from the federal government to Texas in 1983 were $11 billion more than went to the federal government as taxes, the transfer of macroeconomic value from Texas to the U.S. in fuels was $145 billion.

LEADERSHIP

For a period of economic leveling and decline, leadershp is needed to help change attitudes to regard decline as just as much progress towards a prosperous future as growth. Policy initiatives are needed for identifying measures for adapting to the decline, such as diversification, decentralization, improving efficiency, communication, miniaturization, and new land and water ethics. The real frontier for the individual in Texas may not be in space but in a renewed effort to utilize well the resources on earth.

Chapter 1

INTRODUCTION

What is economic development? What roles do the various natural and environmental resources play in sustaining or expanding economic activity? What part do energy, water, land, and labor have in the functioning of our economy, and how do we objectively determine their most productive allocation? Conversely, how do we better determine the real environmental impact of development and the economic costs represented by this impact?

Are these simply rhetorical questions? Hopefully not. This report represents an effort to explore the usefulness of a relatively new method for answering these very kinds of questions. A policy research seminar of the Lyndon Baines Johnson School of Public Affairs worked for two semesters to apply the existing ecological systems analysis approach of Dr. H.T. Odum to Texas economic issues. Dr. Odum, a special visiting professor, and his wife and collaborator, Elisabeth Odum, personally guided the work of the seminar. The study was facilitated by the support of resident faculty member Dr. Marlan Blisset, and the participation of the Texas Department of Agriculture, Office of Natural Resources.

This report summarizes the results of that project and includes some very interesting conclusions about specific policy issues ranging from the farm crisis to the border crisis, from underground to underwater resources, from the state's highways to the state budget. This report also includes a brief introduction to the method of economic evaluation that was employed by the seminar in order to help the reader more fully understand and appreciate the results of the specific policy investigations. We have also included a chapter on methodology because the system itelf can be of value to policy analysts and policymakers as well as to policy students. In some respects, the systems analysis used by this project provides us with a new way of viewing the world in which we live.

In fact, before describing the methodology used, it is useful to share with the reader some of the fundamental premises upon which the energy/economic systems analysis is based.

1. The Universality of Systems. Everything is part of a system and systems are made up of interrelated units. Because of these interrelationships, it is impossible to understand the function and workings of a single part without having a general idea of how all the parts fit together to make a whole. The project itself and this report reflect this in their design. In order to understand the Texas economy, one must have some understanding of its role within the larger U.S. economy. Similarly, within Texas, we can attempt to consider specific problems only within their overall context.

It is also important to note another aspect of the interrelationship of the components that make up an economy. Human and urban systems are ultimately based on their environmental supports--plants producing oxygen and food, stored mineral resources, land and water resources absorbing or processing wastes, and so on. Urban and economic systems cannot be fully understood in isolation from this resource base, the ecological system within which they exist.

2. A common measure is required. In order to compare the worth of different inputs and products of the economy on any scale, it is necessary to develop some common denominator. The measure used in this project is called emergy, a measure of the amount of energy required to generate any particular resource. Some past attempts to reduce economic and environmental elements to units of energy were not successful in modeling or predicting outcomes of events or the success of policies because they did not recognize that all forms of energy do not accomplish equivalent amounts of work.

Emergy is a new term coined to represent both the quantity and the quality of energy that any input or product of the economy represents. This is done by reducing every component of the economic system to solar energy equivalents, the original source of much of our energy. In this way, the amount of energy required to produce an apple can be compared to the energy required to produce a lump of lignite. As will become clear, this also allows us to estimate the relative value of an apple or a lump of lignite to the economy, in terms of the eventual macroeconomic impact of its productive use or consumption.

3. Nature's subsidy has real value. Money paid for resource inputs goes to humans in large part for the work in obtaining those resources and not for the work of the environmental systems that produced them. Social and economic systems tend, therefore, not to give sufficient value to environmental inputs. For example, this study finds that oil, even at what currently are considered relatively high prices, represents 6 times more emergy value to society than does the money paid for its use. Water from the Ogallala represents 10 times more emergy value for the economy than we pay for its extraction. The environment provides a valuable service in terms of waste assimilation too, and we notice this most when the local environment is overloaded and taxes must be raised to pay for man-made waste treatment facilities. The emergy analysis described in this report demonstrates an environmental basis for value.

4. The Maximum Emergy Principle. Social, economic and political systems prevail and excel in competition according to the same general principles as ecological systems. Designs develop that maximize emergy use. In established ecological systems a trial and error selection of self organization process determines what is successful, or what competes and survives. In human systems, human creativity and choice help to find optimum emergy designs.

The most successful systems effectively and efficiently apply a part of their production toward increasing their resources. A tree's survival depends upon applying sufficient effort to establish its root system. Oil companies find it beneficial to reinvest a portion of their income in exploration for new resources. Societies may need to invest a part of their fossil resources in developing alternative resources for the future and in developing housing and transportation systems that can provide needed services for a smaller energy investment. A certain percentage of college graduates must return to teach others. In policy terms, the maximum emergy principle suggests that successful policies are those that optimize beneficial long-term energy use by the economy.

As with the use of any system for modeling the behavior of the real world, this system has shortcomings. Perhaps the primary problem with this system is its novelty and the fact that there is more experience at the ecological than at the social level. A problem inherent in models generally is a lack of data, and given that this is a somewhat new approach to systems modeling, it is sometimes made more difficult by the absence of the right kind of data or data in the appropriate form.

At the same time, we have found that the system employed for analysis by this project has much to recommend it. Particularly because it employs a graphic analysis component, this modelling system allows us to identify and quantify the complex interrelationships of components of the economy. It allows us to compare, on equal grounds, potato chips and microchips, by reducing all inputs and products of the economy to a common energy measurement. And it seems to provide us with reasonable conclusions that compare favorably with much more complex and expensive input-output models that are less flexible.

Chapter 2

METHODS

In this project the United States system, the Texas system, and the subsystems of the economy were studied with a similar methodology.

(A) First a detailed energy systems diagram was drawn as a way to gain an initial network overview, combine information of participants, and organize data-gathering efforts.

(B) Next, an aggregated diagram was generated from the detailed one by grouping components into those believed important to system trends, those of particular interest to current public policy questions, and those to be evaluated as line items.

(C) An emergy analysis table was set up to facilitate calculations of main sources and contributions of the system. Raw data on flows and storage reserves were evaluated in emergy units and macroeconomic dollars to facilitate comparisons and public policy inferences.

(D) From the emergy analysis table emergy indices were calculated to compare systems, predict trends, to suggest which alternatives will deliver more emergy, which will be more efficient, and which will be successful.

(E) For some systems a microcomputer simulation program was written to study the temporal properties of an aggregated model. The program is used as a controlled experiment to study the effects of varying one factor at a time. Insights on sensitivities and trends are suggested from the computer graphs.

(F) Models, evaluations, and simulations were used to consider current public policy questions, determining which alternatives generate more real contributions to the unified economy of humanity and nature.

The chapters in this study include these results for the U.S., for Texas, and for a number of economic subsystems. A short explanation follows on each type of result. See appropriate letter for cross reference with the list above.

(A) DETAILED ENERGY SYSTEMS DIAGRAM

For understanding, for evaluating, and for simulating, our procedures start with diagramming the system of interest, or a subsystem in which a problem exists. This initial diagramming is done in detail with anything put on the paper that can be identified as a relevant influence, even though it is thought to be minor. The first complex diagram is like an inventory. Since the diagram usually includes environment and the economy, it is an organized impact statement.

The following are the steps in the initial diagramming of a system to be evaluated:

1. The boundary of the system is defined.

2. A list of important sources (external causes, external factors, forcing functions) is made.

3. A list of principal component parts believed important considering the scale of the defined system is made.

4. A list of processes (flows, relationships, interactions, production and consumption processes, etc.) is made. Included in these are flows and transactions of money believed to be important.

5. With these lists agreed on as the important aspects of the system and the problem under consideration, the diagram is drawn on the blackboard and on large sheets of paper.

Symbols: The symbols each have rigorous energetic and mathematical meanings (figure 2.1) that are given elsewhere (Odum, 1983). Examples of a system diagram involving both nature and the human economy are given in figures 3.1, 3.2, 4.1, and 4.2.

System Frame: A rectangular box is drawn to represent the boundaries that are selected.

Arrangement of Sources: Any input that crosses the boundary is an energy source, including pure energy flows, materials, information, the genes of living organisms, services, as well as inputs that are destructive. All of these inputs are given a circular symbol. Sources are arranged around the outside border from left to right in order of their energy quality starting with sunlight on the left and information and human services on the right.

Pathway Line: Any flow is represented by a line including pure energy, materials, and information. Money is shown with dashed lines. Lines without barbs flow in proportion to the difference between two forces; they may flow in either direction.

Outflows: Any outflow which still has available potential, materials more concentrated than the environment, or usable information is shown as a pathway from either of the three upper system borders, but not out the bottom.

Adding Pathways: Pathways add their flows when they join or when they go into the same tank. Every flow in or out of a tank must be the same type of flow and measured in the same units.

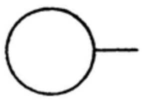
Intersection: Two or more flows that are different, but are both required for a process are drawn to an intersection symbol. The flows to an intersection are connected from left to right in order of their transformity, the lowest quality one connecting to the notched left margin.

Counterclockwise Feedbacks: High-quality outputs from consumers such as information, controls, and scarce materials are fed back from right to left in the diagram. Feedbacks from right to left

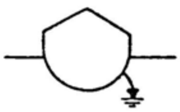
Figure 2.1

Symbols of the Energy Language Used to Represent National Systems in Overview

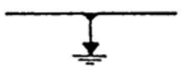
Energy circuit A pathway whose flow is proportional to the quantity in the storage or source upstream.



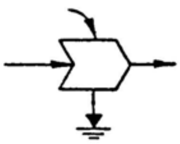
Source Outside source of energy delivering forces according to a program controlled from outside: a forcing function.



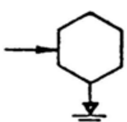
Tank A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.



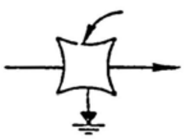
Heat sink Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.



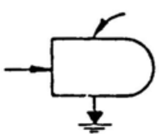
Interaction Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.



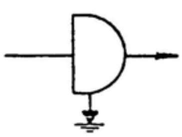
Consumer Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.



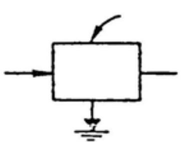
Switching action A symbol that indicates one or more switching actions.



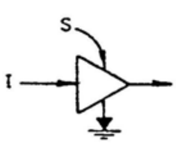
Producer Unit that collects and transforms low-quality energy under control interactions of high-quality flows.



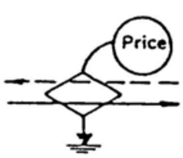
Self-limiting energy receiver A unit that has a self-limiting output when input drives are high because there is a limiting constant quantity of material reacting on a circular pathway within.



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



Constant-gain amplifier A unit that delivers an output in proportion to the input I but changed by a constant factor as long as the energy source S is sufficient.



Transaction A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed). Price is shown as an external source.

Source: Odum, H.T. Systems Ecology. New York, N.Y.: John Wiley. 1983.

represent a loss of concentration because of divergence, the service usually being spread out to a larger area.

Material Balances: Since all inflowing materials either accumulate in system storages or flow out, each inflowing material such as water or money needs to have outflows drawn.

(B) AGGREGATED DIAGRAMS

Aggregated diagrams were simplified from the detailed diagrams, not by leaving things out, but by combining them in aggregated categories. See examples in figure 3.2 for the United States and figure 4.3 for Texas.

Simplified diagrams have the source inputs (cross boundary flows) to be evaluated: environmental inflows (sun, wind, rain, rivers, and geological processes); the purchased resources (fuels, minerals, electricity, foods, fiber, wood); human labor and services; money exchanges; and information flows. Exports are also drawn. Initial evaluations may help in deciding what is important enough to retain as a separate unit in the diagram.

Inside components include the main land use areas; large storages of fuel, water, or soil; the main economic interfaces with environmental resources, and final consumers. Interior circulation of money is not drawn, but all the major flows of money in and out of the systems are shown.

(C) EMERGY ANALYSIS TABLE

An emergy analysis table is prepared with 6 columns with the following headings:

1 Note	2 Item	3 Raw Data	4 Transformity	5 Solar Emergy	6 Macro- economic $

If the table is for flows, it represents flows per unit time (usually per year). If the table is for reserve storages, it included those storages with a turnover time longer than a year.

Column number one is the line item number, which is also the number of the footnote in the table where raw data source is cited and calculations shown.

Column number two is the name of the item, which is also shown on the aggregated diagram.

Column number three is the raw data in joules, grams, or dollars derived from various sources.

Column number four is the transformity in solar emjoules per unit (sej/joule; sej/gram; or sej/dollar, see definition below.) These are obtained from table 2.1.

Column number five is the solar emergy. It is the product of columns three and four.

Column number six is the macroeconomic value in macroeconomic dollars for a selected year. This is obtained by dividing the emergy in column number five by the emergy/dollar ratio for the selected year. The emergy/dollar ratio is obtained by dividing the gross national product by the total contributing emergy use by the combined economy of man and nature in that country that year.

(D) EMERGY INDICES

The following are emergy indices used to draw inferences from emergy analyses.

The solar transformity of an object or resource is the equivalent solar energy that would be required to generate (create) a unit of that object or resource efficiently and rapidly. Figure 2.2 shows a chain of energy transformations and the solar transformities for the products of each progressive transformation. A solar transformity is calculated by dividing the input of solar energy by the output of energy of another type.

In the example in figure 2.2, a very large amount (159,000 joules) of relatively diffuse solar radiation and geological processes driven by deep heat sources is required to warm the continents and oceans, thereby producing the evaporation and tradewinds that produce only 10.3 joules of rain energy over the Amazon. Solar energy received by the earth is transformed to lower grade heat, maintains the planet's temperature, and is radiated back out to space. The energy manifests itself as only 4.6 joules of biomass growth in the form of wood, which finally, after harvest and drying, can produce only one joule of electric power for Brazil's industrial economy. Calculating the solar transformities, as shown below, simply shows that a joule of rain is worth over 15,000 times a joule of solar energy. The value of a joule of electric energy is 150,000 times the value of a solar energy joule.

Table 2.1 contains transformities calculated for various items. Each of these was derived from a previous emergy subsystem analysis. If none is available for a commodity, a special analysis of the systems producing that item is conducted to add all the input flows in solar emergy units required to generate a unit of that type. Transformities are an energy-based natural scale of value. Transformities facilitate calculations of emergy and macroeconomic value.

The net emergy ratio is the emergy of an output divided by the emergy of those inputs to the process that are fed back from the economy (see figure 2.3). This ratio indicates whether the process can compete in supplying a primary energy source for an economy. Recently the ratio for typical competitive sources of fuels has been about 6 to 1. Processes yielding less than this are not economic as primary emergy sources.

Table 2.1

Transformities

Energy or material		Solar emjoules per dollar	Solar emjoules per joule	Solar emjoules per gram
Average service, U.S.	1983	2.4 E12		
Average service, Texas	1983	2.6 E12		
Average service, Mexico	1983	2.9 E12		
Solar energy			1.0	
Uranium-generated heat			1.79 E3	
Wind, kinetic energy			6.23 E3	
Rain, physical energy against gravity			8.89 E3	
Rain, chemical potential over land			1.54 E4	
River flow against gravity			2.36 E4	
Tides			2.36 E4	
Waves absorbed at shore			2.59 E4	
Earth cycle			2.90 E4	
Wood			3.49 E4	
Coal			3.98 E4	
River water			4.1 E4	
Natural gas			4.8 E4	
Oil			5.3 E4	
Topsoil in place			6.3 E4	
Corn, industrial agriculture			6.8 E4	
Labor, primitive			8.1 E4	
Water, groundwater[1]			1.10 E5	
Electricity			1.59 E5	
Meat, sheep			1.71 E6	
Nitrogen fertilizer			1.69 E6	
Potassium fertilizer			2.62 E6	
Wool			3.8 E6	
Steel				1.78 E9
Machinery				6.7 E9
Phosphate Rock				1.41 E10
Aluminum ingots				1.63 E10
Bauxite				8.5 E8
Earth (clay)				1.71 E9
Gold[2]				4.38 E14

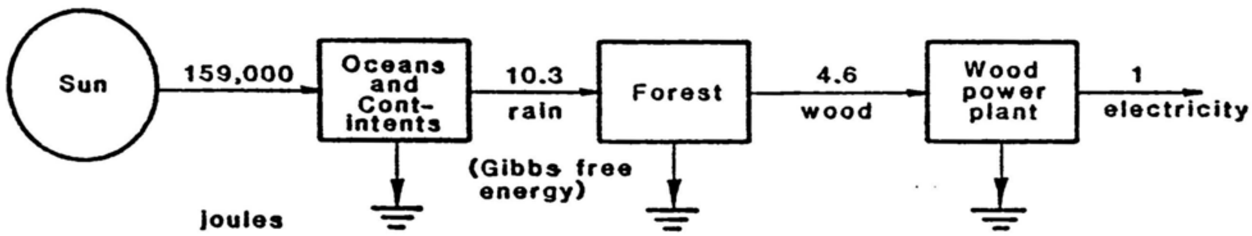
Source: Odum, H.T. and E.C. Odum. 1983. Energy Analysis Overview of Nations. WP-83-82. International Institute for Applied Systems Analysis, Laxenburg, Austria.

[1] Figure 5.1.

[2] Bhatt, R. "Policy Implications of Gold Emergy." Unpublished student report for Policy Research Project course, LBJ School of Public Affairs, The University of Texas at Austin. 1986. pp. 158-168.

Figure 2.2

Example of Chain of Energy Transformations in a Wood Power Plant at Jari, Brazil



Solar emergy of these flows is 159,000 solar emjoules/unit time.

Solar Transformities in solar emjoules per joule (sej/j):

Rain: $\frac{\text{159,000 solar joules}}{\text{10.3 rain joules}}$ = 1.54 E4 sej/j

Wood: $\frac{\text{159,000 solar joules}}{\text{4.6 wood joules}}$ = 3.46 E4 sej/j

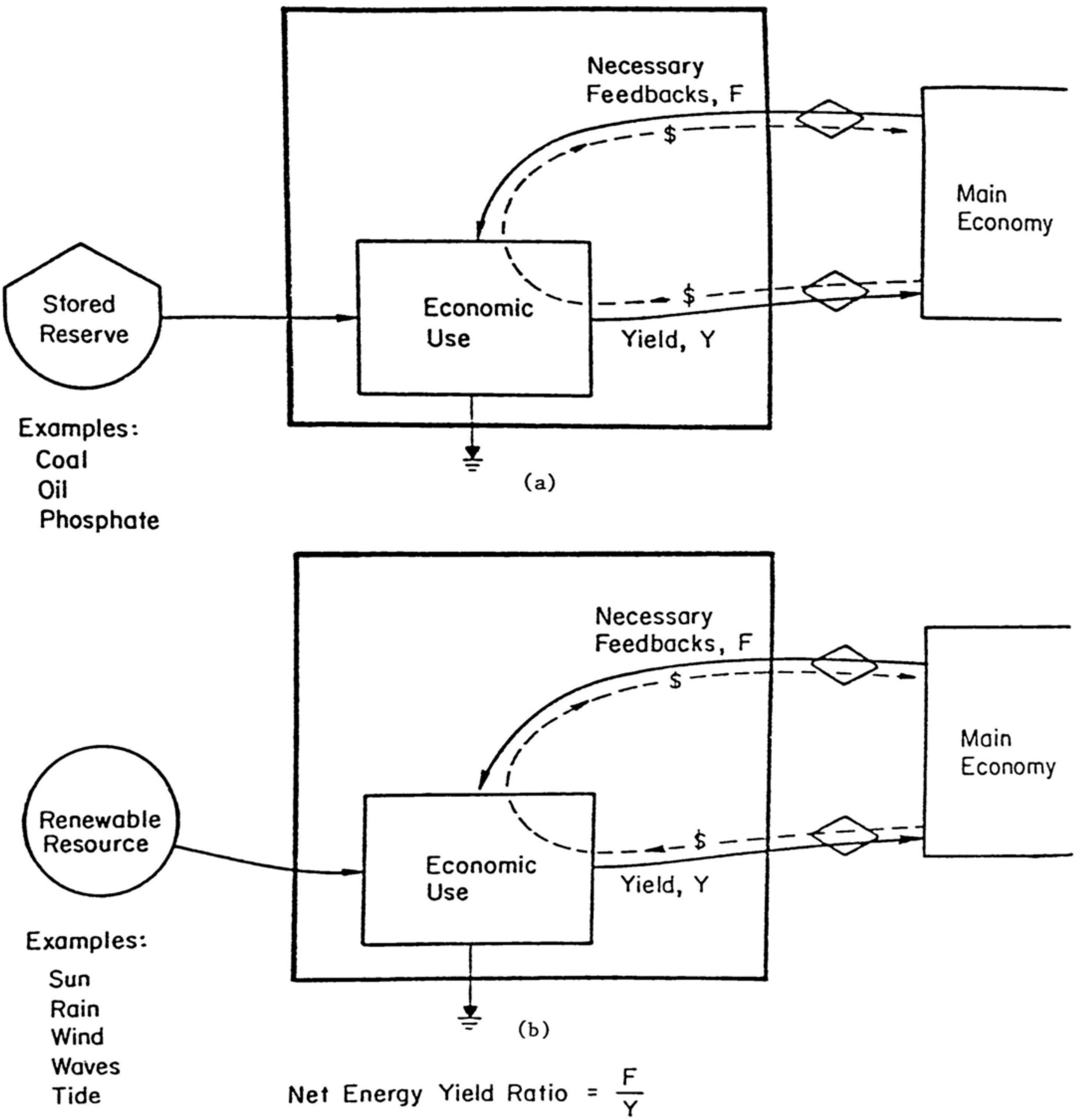
Electricity: $\frac{\text{159,000 solar joules}}{\text{1 electricity joules}}$ = 15.9 E4 sej/j

Source: Odum, H.T. and E.C. Odum, eds. Energy Analysis Overview of Nations. Working Paper, WP-83-82. International Institute for Applied Systems Analysis, Laxenburg, Austria. 1983.

Note: Calculation of solar transformities: 159,000 solar joules is the direct solar energy and the solar equivalents of the earth's deep heat sources affecting earth processes that generate 10.3 joules of chemical potential energy in the rain that grows 4.6 joules of wood that generates one joule of electricity. For details see Odum and Odum, 1983.

Figure 2.3

Net Emergy Yield Ratio for Evaluating Primary Energy Sources



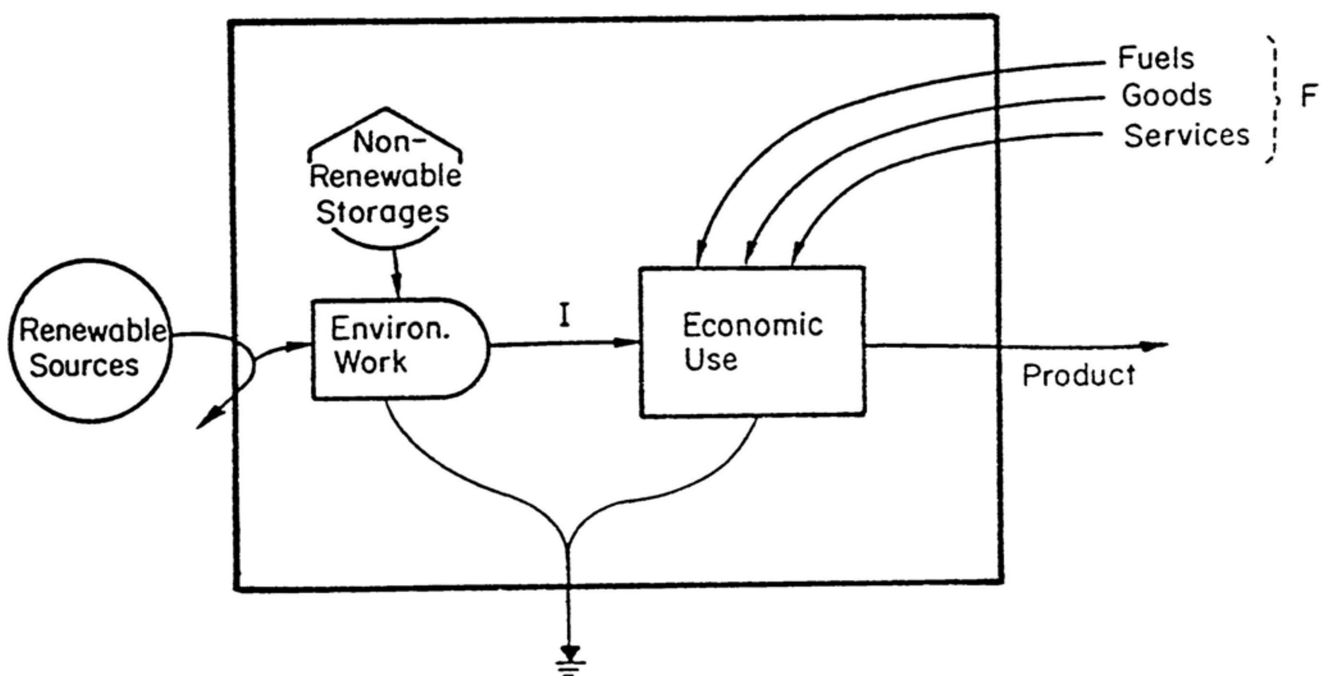
Source: Odum, H.T. and E.C. Odum, eds. Energy Analysis Overview of Nations. Working Paper, WP-83-82. International Institute for Applied Systems Analysis, Laxenburg, Austria. 1983.

Note: Both F and Y should be in solar emergy units.

The emergy investment ratio is the ratio of the emergy fed back from the economy to the emergy inputs from the free environment (see figure 2.4). This ratio indicates if the process is economical as utilizer of the economy's investments in comparison to alternatives. To be economical, the process should have a similar ratio to its competitors. If it receives less from the economy, the ratio is less and its prices are less so that it will tend to compete in the market. Its prices are less when it is receiving a higher percentage of its useful work free from the environment than its competitors.

Figure 2.4

Emergy Investment Ratio for Evaluating Whether Matching of Investments with Environmental Contributions is Competitive



$$\text{Emergy Investment Ratio} = \frac{F}{I}$$

Source: Odum, H.T. and E.C. Odum, eds. Energy Analysis Overview of Nations. Working Paper, WP-83-82. Internatonal Institute for Applied Systems Analysis, Laxenburg, Austria. 1983.

Note: I and F should both be in solar emergy units.

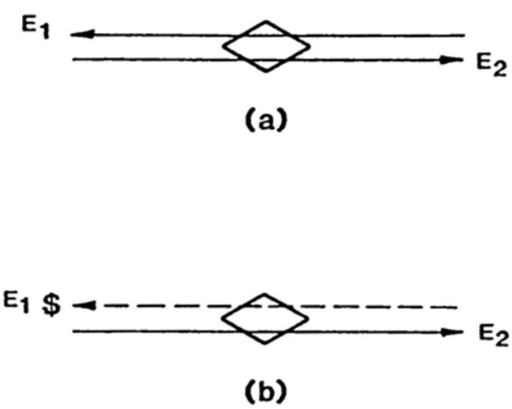
However, operation at a low investment ratio uses less of the attracted investment than is possible. The tendency will be to increase the purchased inputs so as to process more output and more money. The tendency is towards optimum resources use.

Thus, operations above or below the regional investment ratio will tend to change towards the investment ratio.

The <u>emergy exchange ratio</u> is the ratio of emergy received for emergy delivered in a trade or sales transaction (see figure 2.5). For example, a trade of grain for oil can be expressed in emergy units. The area receiving the larger emergy receives the larger value and has its economy stimulated more. Raw products such as minerals, rural products from agriculture, fisheries, and forestry, all tend to have high emergy exchange ratios when sold at market price. This is a result of money being paid for human services and not for the extensive work of nature that went into these products.

Figure 2.5

Exchange Ratio of Energy Flows of a Trade



$$\text{Emergy exchange ratio} = \frac{E_2}{E_1}$$

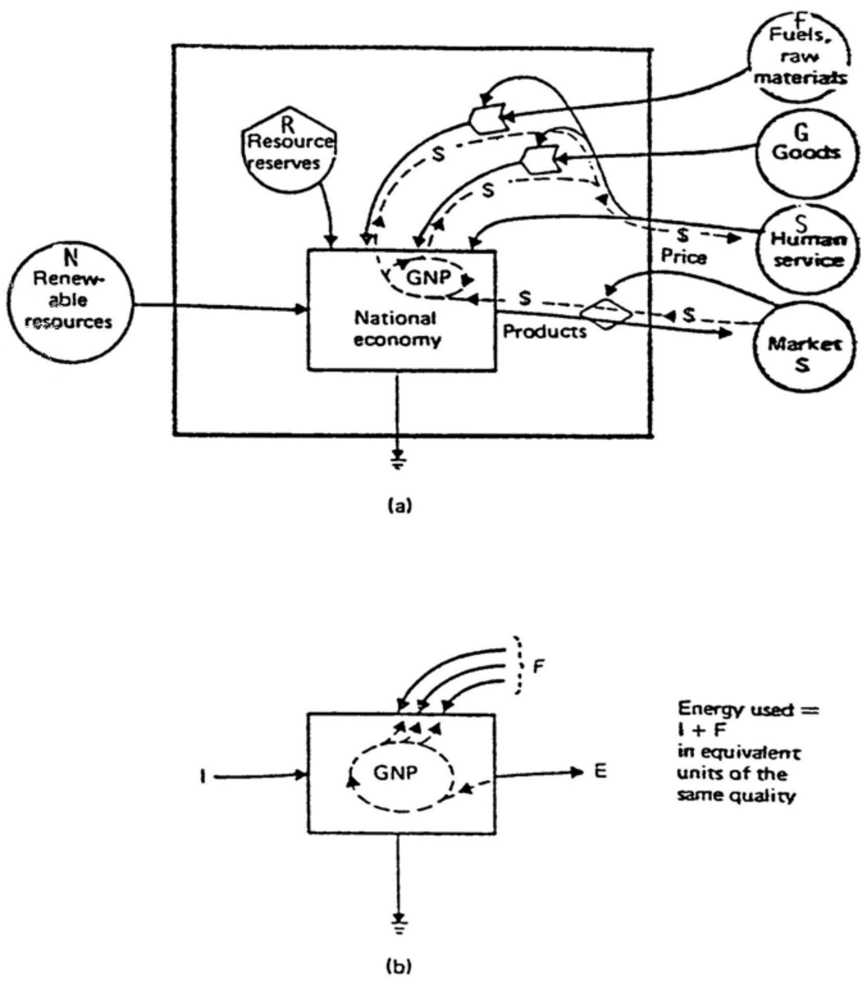
Note: (a) Trade of two commodities; (b) sale of a commodity.

The emergy/dollar ratio for a country and a particular year is the ratio of the total emergy used by the country from all sources divided by the gross national product for that year (see figure 2.6). As the diagram shows, it includes emergy used in renewable environmental resources such as rain, non-renewable resources used such as fuel reserves and soil, imported resources, and imported goods and services. Rural countries have a higher emergy/dollar ratio because more of their economy involves direct environmental resource inputs not paid for.

The term macroeconomic value refers to the total amount of dollar flow generated in the entire economy by a given amount of emergy input. It is calculated by dividing the emergy input by the emergy/dollar ratio.

Figure 2.6

Overview Diagram of a National Economy



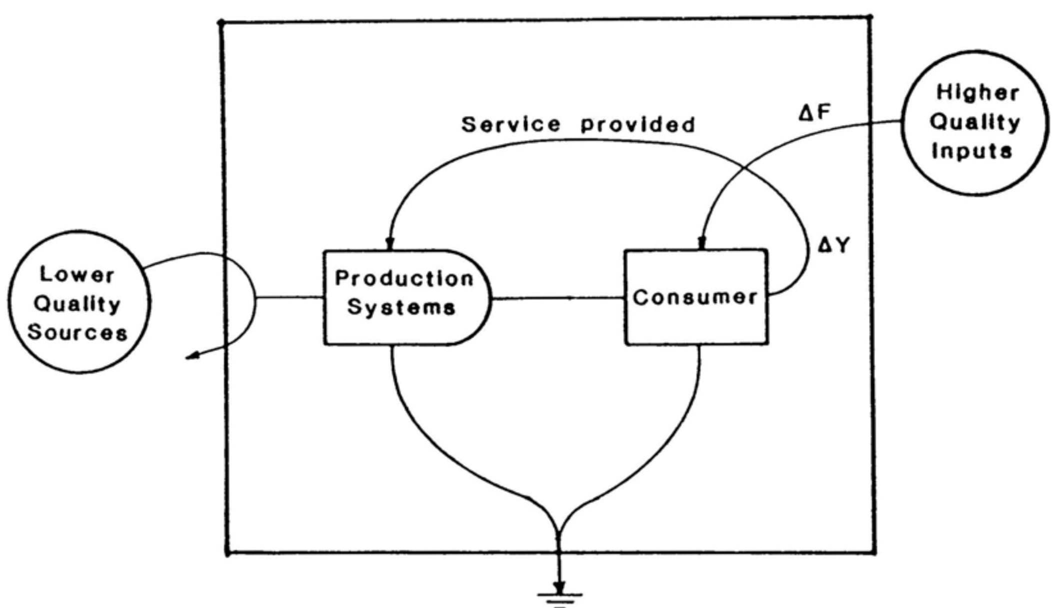
Source: Odum, H.T. and E.C. Odum, eds. Energy Analysis Overview of Nations. Working Paper, WP-83-82. International Institute for Applied Systems Analysis, Laxenburg, Austria. 1983.

Note: (a) Main flows of dollars and energy; (b) summary of procedure for summing solar emergy inflows.

The <u>emergy amplifier ratio</u> is the emergy increase produced in some process compared to an emergy increase applied. In figure 2.7, an increase in emergy causes increase in yielded emergy. The ratio is a measure of efficiency of the applied action. For example, increasing health services for the working population to some optimum point will maximize productive work hours available.

Figure 2.7

Emergy Amplifier Ratio



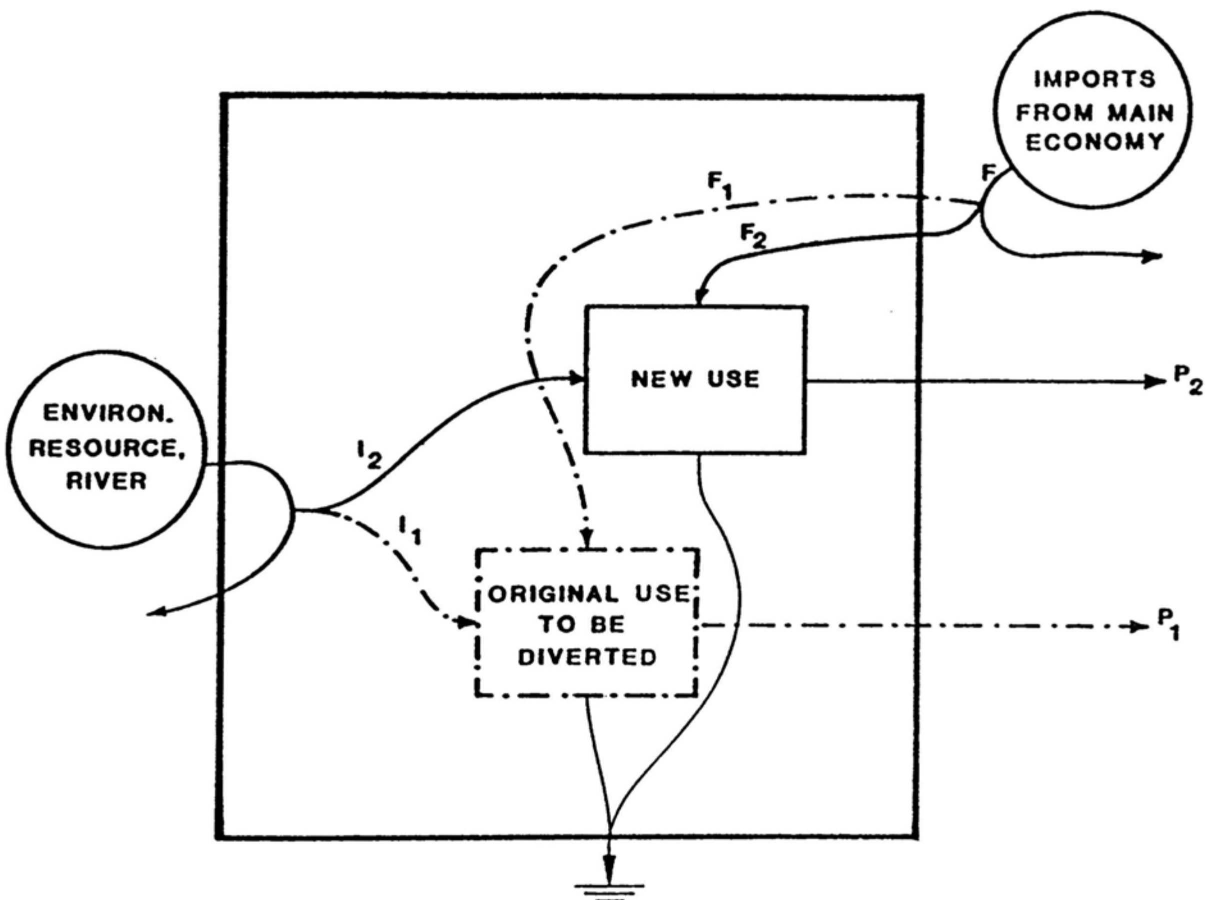
EMERGY Amplifier Ratio $\frac{\Delta Y}{\Delta F} = \frac{\text{Service increase}}{\text{Investment increase*}}$

*High quality feedback

The alternative benefit ratio is used to make decisions between investment options available. Selecting different options for a given investment creates different systems within which each can be evaluated. This ratio should be used in a two-step comparison. First compare the emergy contributions of the alternatives. In figure 2.8, P is the sum of the free environmental emergy, I, and the attracted investment emergy from the economy, F. In the diagram, P2 is predicted to out compete, or prevail over P1 if its emergy is higher.

Figure 2.8

Comparison of Alternative Emergy Benefits of Two Systems



Note: Contribution of each P is the sum of its environmental input I and its economic inputs feedback F.

A second comparison must then be made to assure that the investment that appears to be the best alternative among a set of options considered is also reasonably attractive compared with the average regional competitive investment ratio. In the United States and Texas the competitive investment ratio for purchased goods and services (not source inputs) is about 7 to 1 (the ratio of I to F in figure 2.8). This represents the fact that, in highly industrialized society, it requires about 7 units of paid goods and services for every unit of environmentally contributed input to generate products in our economy. The alternative which has the highest emergy contribution must also have an investment ratio of about 7/1 or less in order to survive or succeed. Otherwise, resources will gravitate to more productive options. The alternative benefit ratio is represented as the ratio of the output (P) of a specific option to the average investment (F avg.) for the region, a higher number representing an option more likely to succeed.

Various emergy indices of an economy are useful for comparing states and nations. These include:

Emergy flow per person is a measure of the standard of living that includes unpaid inputs.

Emergy flow per area is a measure of spatial concentration of an economy.

Emergy carrying capacity is the sum of the renewable environmental emergy flow plus an attracted emergy flow from the economy equal to the competitive investment ratio times the environmental flow, and is a measure of the total macroeconomic activity that can be supported by the resources available to a region.

Fraction of total emergy that is indigenous is an index of self sufficiency.

(E) MICROCOMPUTER SIMULATION

In order to develop simulations of various systems considered, energy systems diagrams were aggregated so as to retain the total resource and service inputs and the main structure of production and consumption of the economy. Components and processes of particular interest are retained separately. Money flows across the boundary were diagrammed explicitly.

A copy of the diagram was used to write flows and storages, usually in raw units, using data already gathered for the emergy analysis.

Then equations were written--equations which are automatic translations of the symbols (1).

The program was written in BASIC. For nations and states Odum developed a generic program which is readily adapted with new data to new locations.

After the program is running, one variable is changed at a time to study effects as a controlled experiment. In this study changes in oil prices were made at appropriate times in the run, simulating some recent events.

(F) PUBLIC POLICY QUESTIONS

Various policy questions were examined by comparing emergy contributions of alternatives. The alternatives with higher emergy flows represent solutions that will tend to prevail because their contribution to the economy is richer. The presumption is that through trial and error as well as through rational argument, alternatives are tried so that their utility can be observed by the public decision process. Ultimately, people will come to accept the high emergy alternatives because these succeed and survive. By doing the emergy analysis in advance, one is able to predict what will eventually be the accepted policy.

ENDNOTES

(1) For procedures see Odum, H.T. Systems Ecology. New York: John Wiley, 1983, chapters 3-6.

Chapter 3

OVERVIEW OF THE UNITED STATES ECONOMY

This study is primarily concerned with the resource status of the state of Texas. However, consideration of the U.S. was undertaken to identify larger overall trends in emergy flows and emergy storages that might affect Texas. As a tree will use a root to optimize its own growth and survival, so Texas will feel the pressures of the larger economic system to maximize its own prosperity. As we have seen, for example, in past years, the U.S. prefers to keep energy costs as low as possible for industrial stimulation, and to preserve competitiveness with other countries, although this puts resources from Texas in the position of subsidizing (providing net emergy income to) the production and commerce, and inefficiency in some cases, of the country.

Figure 3.1 represents an aggregated systems diagram of the main emergy flows and processes identified in the U.S. as a result of our investigation and discussion. Figure 3.2 further summarizes the nature and scale of those flows and processes. Tables 3.1 through 3.3 present an evaluation of the resource base and the export and dollar flows of the economy, and selected indices calculated in an effort to better comprehend overall patterns. The project was limited to use of 1983 data in order to have comparable data on all the critical items for a single recent year. An overview simulation model of the United States was used to relate the availability of resources to economic growth. The graph of trends produced by the simulation helps us visualize national trends that will affect Texas.

THE RESOURCE BASIS FOR THE ECONOMY

From our examination of this information and the graphic representation of the data in the systems diagrams, it becomes apparent that fuel use in this country is the principal source for the economy's operation, although substantial inflows of emergy come from renewable resource inputs, especially rain, and from imported goods and services. Specifically, the U.S. operates based upon 10 percent renewable resources, 66 percent resources mined from within its own borders, 9 percent from fuels and other raw resources imported, and 15 percent imported goods and services.

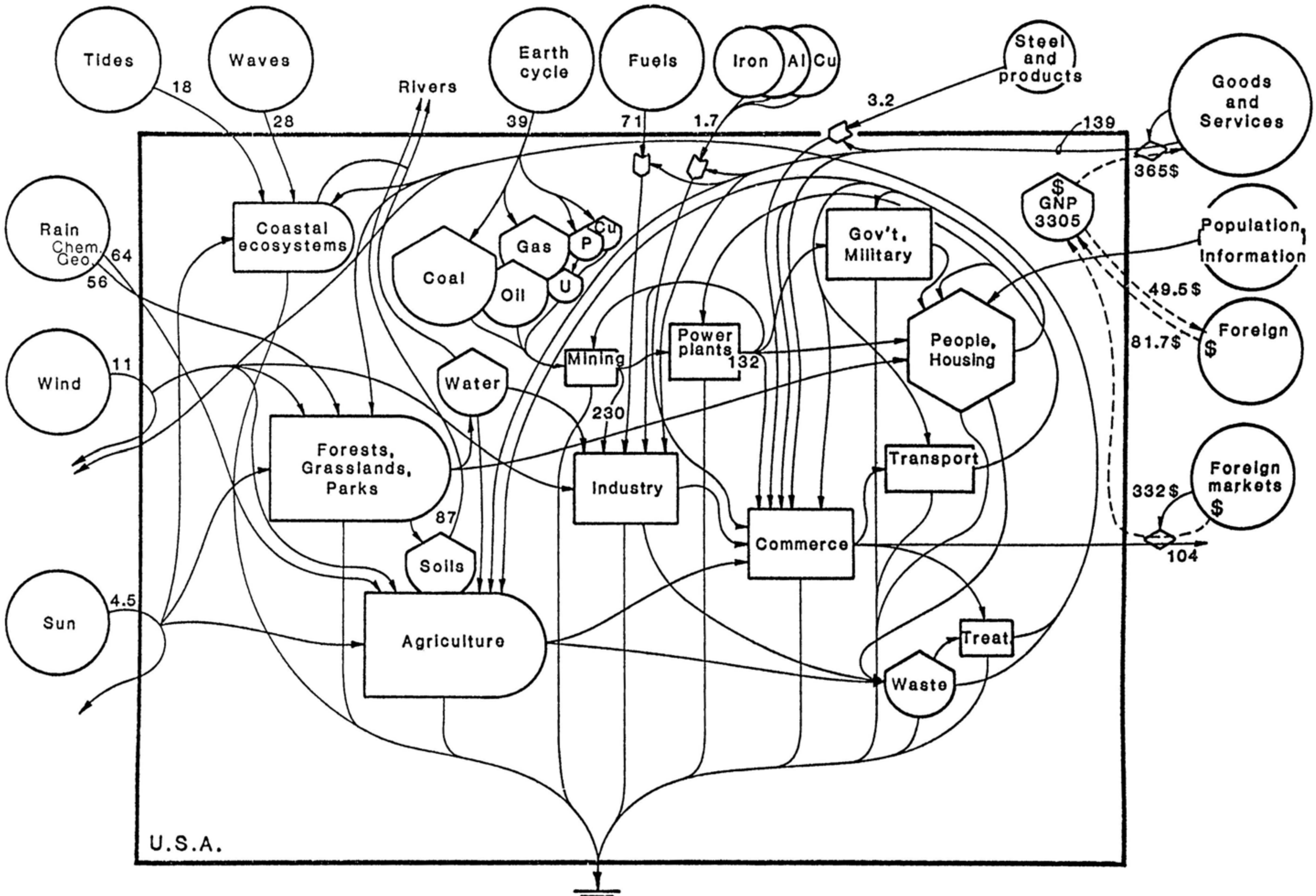
These figures provide an accurate comparison of the country's self-reliance versus its dependence on other countries, as well as its reliance on nonrenewable versus renewable fuels or minerals. For example, it can be seen that the U.S. is approximately 76 percent self-reliant based on emergy as compared to 89 percent calculated from dollar flows. The USSR by comparison is roughly 97 percent self-sufficient.

At the same time it must be acknowledged that the U.S. is currently benefiting in net emergy terms from imports. If emergy-rich raw resources, goods and services now being imported to this country were no longer available, or their cost rises to equal their emergy value, the reduction in our economy would be about 24 percent. Simply eliminating the importation of fuels and raw materials would bring a 10 percent reduction.

Similarly, it can be seen that when worldwide shortages eventually force nations to operate on renewable resources alone, the country's economy would have to be one-tenth its present size, or our standard of living would have to be one-tenth its present level at current population levels.

Figure 3.1

Energy Systems Diagram of the United States of America

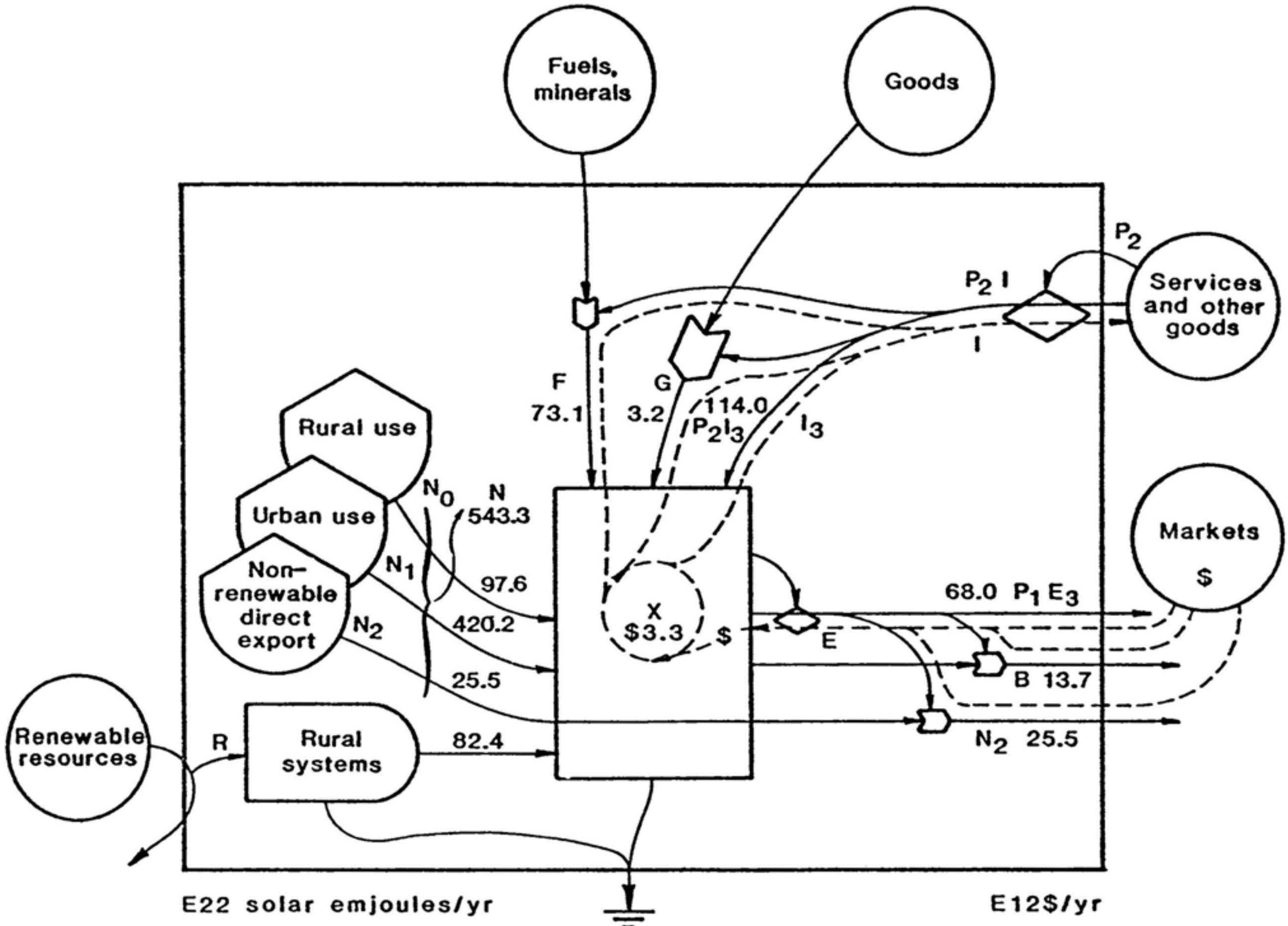


22

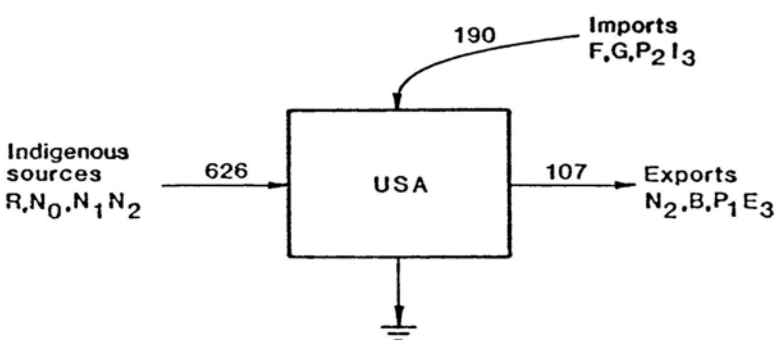
Note: Energy network symbols are given in figure 2.1. Numerical values of emergy and dollars for these pathways and storages are given in appendix 4. Dashed lines are money flows.

Figure 3.2

Summary of Emergy Flows for the United States of America in 1983



(a)



(b)

Note: Flows are in solar emergy units. Letters are flows in table 3.4.

Table 3.1

Macroeconomic Value of Inputs to the U.S. Economy in 1983.

Item	$ per year (billions)
RENEWABLE SOURCE	
Rain, chemical potential energy	268
Rain, geopotential energy	234
Earth cycle	164
Waves	117
Hydroelectricity	79
Tide	75
Wood consumption	64
Wind, kinetic energy	45
Direct sunlight	19
IMPORTS	
Goods and services	578
Crude oil	168
Petroleum products	109
Natural gas	20
Iron and steel products	13
Iron ore	5
Bauxite	3
NONRENEWABLE SOURCES WITHIN U.S.A.	
Oil	771
Soil loss as part of use	418
Coal	388
Natural gas	370
Nuclear electric	70
Phosphate	90
Iron ore	13
Uranium	5

Note: For details of calculations, see appendix 1. Some of these are byproducts of common sources and therefore should not be added.

Overviews of international exchange obtained with the systems diagram affect our view of import regulations and tariffs. Tariffs reduce the raw materials that supply the nation with the high net emergy flows which are the principal basis of prosperity of the U.S. as well as of most other developed countries. It is recognized that policy trade-offs must be made to retain domestic production capacity in critical industries like agriculture and energy, but the economic contribution of material imports should also be recognized when considering policy options.

It is inevitable that as nonrenewable raw material sources decline, more resources will have to be allocated for mining, concentrating, or processing. This will leave less for the rest of the economy. To the extent that the net emergy of resources drops worldwide as a result, all economies will receive proportionately less subsidy to support other economic activities which are not net emergy producers.

In the near term, because we are a relatively developed country, the net emergy of domestic resources will be less than that for foreign resources. To the extent industry is dependent upon these lower emergy-per-dollar domestic resources, it will also become less competitive internationally. We see this already for oil, as most U.S. crude production appears to be only marginally competitive with low-cost oil from the middle east.

STORED RESOURCES

Table 3.2 evaluates resource reserves still in the ground. Some idea of the time required to deplete these is given in column two by dividing these reserves by the current rate of use. Coal at present use might last 500 years. If it were used for all fuel needs for present economic activity it would last 106 years ($194,025 divided by the sum of fuel uses in table 3.1, $1826/yr). Some of these deposits are deep so that the net yield would be less and the duration of use also less. Some economic assets, particularly infrastructure have longer use times, 50 years or more. See Texas highway discussion (chapter 6).

Table 3.2

Macroeconomic Value of Storage Reserves of the U.S.A. in 1983.

Item	$ (billions)	Years Remaining
Coal	194,025	500
Economic assets	66,000	23
Topsoil	19,293	46
Natural gas	4,340	12
Petroleum	3,776	5
Ground water	3,211	-
Phosphate	1,057	12
Wood biomass	686	-
Uranium	220	44

Note: For details of calculations, see appendix 2. Years of supply were estimated by dividing macroeconomic value in the first column by the rates of use in table 3.1. Economic assets were divided by total sources used per year in table 3.3.

Table 3.3

Macroeconomic Characteristics of the U.S. Economy in 1983.

Item	$ per year (billions)
Sources	
Renewable sources	343
Imports	332
Nonrenewable sources used	2228
Total	2903
Exports	
Services	332
Fuels, corn, iron, wood, nitrogen, phosphorus	163
Total	495

Note: For details of calculations of emergy and macroecoomic equivalents, see appendices 3-5.

FOREIGN COMPETITION

In addition to a declining net emergy ratio at home, there are several other important factors that affect our competitiveness worldwide. The attractiveness of our products overseas depends finally upon their price. Low competitive price depends on having more free inputs to the production processes. The ratio of purchased inputs to free resource inputs for manufactured goods within the U.S. is currently about 7 to 1. This is much higher than most developing countries.

Several trends within the U.S.A. will tend to increase the relative price of our products. Policies and investment patterns developed during a period of history when growth was occurring may not be appropriate during a period of constricting or declining emergy availability (per capita or per area). Growth periods create opportunities for increasing economies of scale, especially when the supply of cheap (high net emergy) fuels and raw materials are also expanding. The fast growth of the U.S. early in this century allowed it to out-compete other countries and maintain a large share of world emergy and world markets. This allowed people in the U.S. to spend a larger amount of money (emergy) on not only larger tractors and larger companies and larger power plants, but also on luxuries, or items that do not provide any high emergy feedback to improve or maintain the productivity of the economy. Examples of this include too large (relative to the need fullfilled) automobiles, homes, and excesses like the misuse of alcohol and illegal drugs.

Increasing population density, or emergy per area and per person stretches resources, and increases the public costs (taxes) required to provide services, including services once provided by nature and the environment. A particularly important example of this is the value of the environment for waste assimilation.

DEFENSE

Defense spending maintains an international sphere of influence that promotes or facilitates trading. To date, the U.S. has benefited from maintaining this umbrella, but as the country's share of the world's total emergy decreases, it becomes more difficult to maintain, and will have to be withdrawn, either through voluntary action or loss of influence via conflict. If retraction of our military umbrella comes through conflict (loss of a war, for example), the cost to the economy will be an unnecessarily large loss of emergy consumption of raw resources, increases in taxes, loss of competitiveness, and an overall decline in the standard of living. Already, defense spending increases this country's overhead costs that other countries with relatively less defense expense don't have, making it easier for them to compete.

Ascertaining the appropriate, optimum sphere of influence for our defense system would require a great deal more research than was possible in this overview of the U.S. A separate investigation of the defense industry which was performed by P. Dalton (1), however, indicated that at present the U.S. defense budget consumes roughly 8 percent of the national emergy budget, and about 3 percent directly for maintaining the umbrella under which we receive in commerce about 24 percent of our total or gross national product. So, although defense expenditures are large, the U.S. uses about three macroeconomic dollars of trade for every macroeconomic dollar spend on defense, and about eight macroeconomic dollars for every macroeconomic dollar spent supporting our sphere of influence. To the extent that we could maintain the present trade relations and sphere of influence for less expenditure, we could increase the effeciency of our economy. Relying less on materials- and energy-intensive solutions could reduce the emergy cost of defense. In addition, as the U.S. retracts, or is forced to retract, its military umbrella--in proportion to our declining share of world emergy flow--and we let (or force) Korea, Japan, Western Europe or other competitors to help maintain open trade relations, we will find ourselves more price competitive.

POLICY IMPLICATIONS

As noted, other less developed competing countries, with more free resource inputs, lower defense costs, and less dependence upon relative luxuries, will be able to charge lower prices for similar goods and services and even for raw materials, although they will also find that increasing their internal use of raw materials to produce finished goods and services will improve their economy further. The tendency therefore will be for the U.S. to lose market share to these developing countries until their living standards, their levels of resource contributions, and their levels of defense expenditures are all comparable.

Because the country's emergy storages are still relatively large, and net emergy ratios are still large, efficiency can help maintain our standard of living. However, adjustments must be made to account for the decrease in net emergy that probably will be available. Learning to make these adjustments gracefully will provide the most certain way to maintain high living standards, although it may mean revising our concepts of high living standards.

It is clear from the changes taking place in the economy that the scale of economy for the present period is smaller than it has been recently. For the near term, smaller farms with smaller tractors, more productive and increased use of labor and land, with much less high-emergy chemical and fuels inputs will help the agriculture industry make a transition to a production mode that is sustainable. Smaller cars, smaller decentralized power production and cogeneration, energy and water conservation, effective use of communications and information high technology, and other changes that increase the efficiency of economic processes will help slow the loss of international competitiveness and maintain production and jobs in our economy. The relationship of Texas with Mexico and the Maquiladores provide a rich example to consider in more detail in this regard (see chapter 4).

Implications for the Texas economy grow out of our characterization of the national economy. It would appear that transfer payments for defense establishments in Texas must eventually decline, as will tourist travel. When oil and gas prices inevitably begin their upward climb, Texas will receive some windfall, but for a substantial amount of time, Texas oil reserves may be less attractive to the economy than cheaper foreign resources. Lower-cost agriculture in developing countries will provide stiff competition for domestic producers. The same will hold true for manufacturing. Environmental policies will increase pressure to reduce waste in the system and recycle. Throw-away materials and waste disposal will become less prevalant. The differential in living standards between the U.S. and many other nations may decrease, reducing immigration pressures. This relative change will be slowed by the fact that population growth in developing countries outpaces economic development.

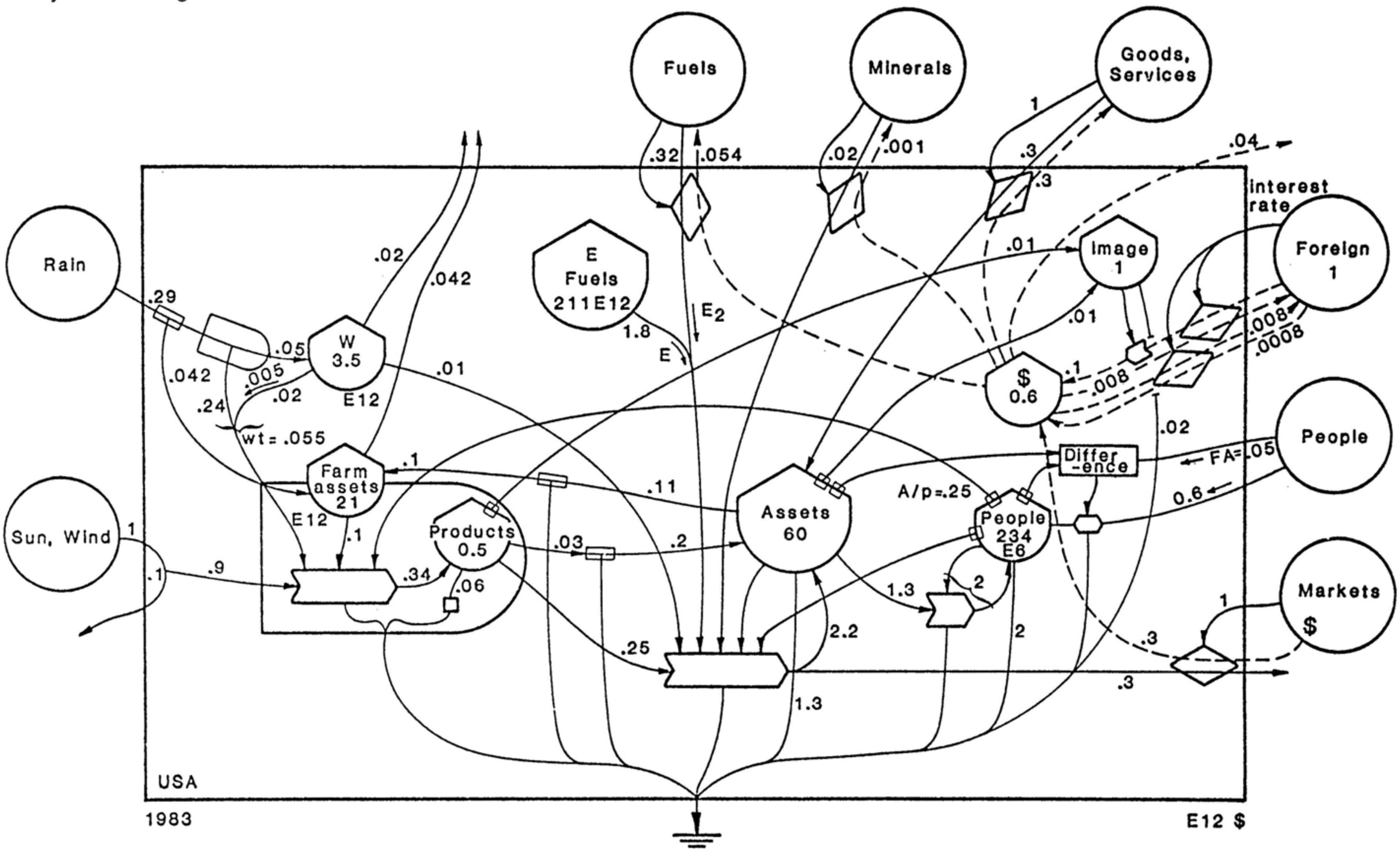
SIMULATION MODEL OF THE UNITED STATES

The systems diagram of the United States in figure 3.1 was simplified by further aggregation in figure 3.3. The model shows the assets of the country generated by production processes that utilize sun, wind, and rain from the local environment interacting with fuels and minerals from within the country and from imports. In the model, favorable national image is generated from rural products and urban assets, and a favorable image draws foreign investments. The model shows births, deaths, and immigration in proportion to the difference between assets per person in the U.S. and that outside. In the model, money (in dashed lines) received from sales and investments goes out to purchase goods, services, minerals, fuels, and military services. The model's mathematical equations for these relationships are given in appendix 6 and the computer programs in appendices 7 and 8.

When calibrated with the data assembled in this study, the simulation of the overview model of the U.S.A. (figure 3.3) produces graphs of growth, leveling, and downturn to a lower economic level as fuels become less

Figure 3.3

Systems Diagram of the Simulation Model of the United States Showing Numerical Values Used for Calibration

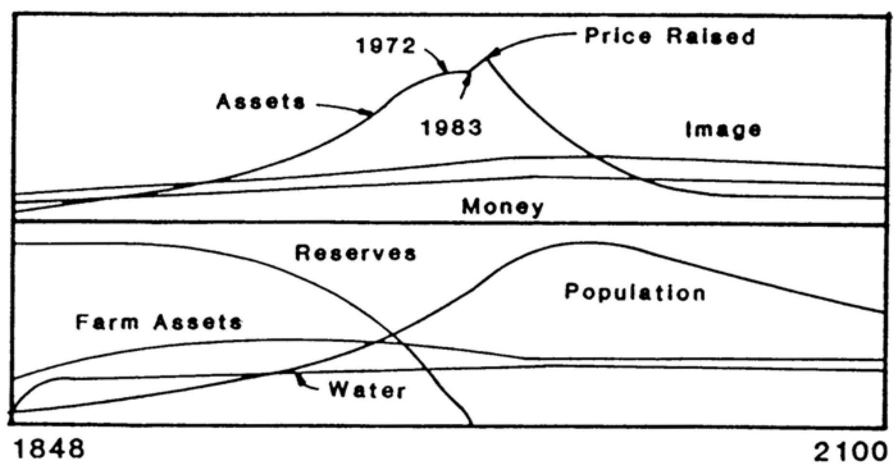


Note: See appendices 6 and 7 for storage and pathway letters used in the mathematical equations of the model listed in appendices 6-8.

available. One simulation result is the scenario in figure 3.4. Oil prices were increased as the simulation reached 1972, decreased again as the simulation reached 1983 and increased again in 1990. In this scenario economic decline resulted, but population kept increasing for a time, causing a sharp decline in standard of living. We need not remind the reader that model simulations are not predictions of the future or the real world, but are an indication of what would happen if the factors put into the model were correct and the only ones.

Figure 3.4

Graph from Simulation of the U.S. Economy with the Model in Figure 3.3



Note: Events included low oil price initially, price rise in 1973, price drop in 1985 and increase in price thereafter.

Common to all the simulations is a growth and decline, but the timing of the final turndown depends on the rate of depreciation of our system, which is not a quantity which is yet established. The faster the depreciation rate, the more of our resources it takes to maintain things, the sooner things peak, and the faster they can decline. Without replacement, highways and people last 50 to 90 years. How long does a nation's information and culture remain without replacement? As part of our policy research project, very innovative calculations were made of the emergy in human information and technology by A. Brown (2), which are the beginnings of research needed to answer these questions, but the details are beyond the scope of this report.

All of the computer simulation runs for the U.S.A. made with various conditions suggest that the Texas system may be influenced strongly in the near future by the timing of the leveling and decline of national power and assets caused by worldwide resource depletion. Consider next the Texas state system.

ENDNOTES

(1) Dalton, P. "Defense Analysis" (unpublished student report for Policy Research Project course, The University of Texas at Austin, LBJ School of Public Affairs, 1986), pp. 184-199.

(2) Brown, A. "Research Information and High-tech Manufacturing" (unpublished student report for Policy Research Project course, The University of Texas at Austin, LBJ School of Public Affairs, 1986), pp. 184-199.

Chapter 4

OVERVIEW OF THE TEXAS ECONOMY

Texas is a large state with grassy plains to the north; rainy forested zones to the east; desert and mountains on the west; marine estuaries and coastal resources to the southeast; and a major foreign country along its southern border. Its traditional economy of oil, gas, and petrochemicals; cattle; timber; grains and cotton; and defense is rapidly changing. Declining oil availability and competition from cheaper foreign oil are the primary factors altering the resource basis of the economy of Texas. Still, its population is expanding with immigration from other states and Mexico. A systems overview, together with an emergy evaluation of the main contributors to the economy, may help demonstrate trends and suggest policies for maintaining a vital economy in times of diminishing resources.

COMPONENTS OF THE TEXAS ECONOMY

Sources and Sectors

Figure 4.1 is a systems diagram of the main components of the economy of man and nature in Texas. The causal influences from outside sources are shown as circular symbols, and the main sectors and productive interactions are shown within the frame that represents the Texas boundary. Areas of wilderness, range, intensive agriculture, and coastal waters are shown developing products on the left. Mining and electric power production draw fuels from reserves and from imports to generate the power and transportation sectors shown in the center, and consumers, government, education, and finance are on the right. The main components of figure 4.1 are given emergy values based upon detailed calculations included in the technical appendices (appendices 9-13). An aggregated diagram of the Texas economy is shown in figure 4.2a. The summary of emergy flows for the state's economic system is provided in table 4.1, which accompanies the aggregated diagrams.

Emergy Flows and Storages

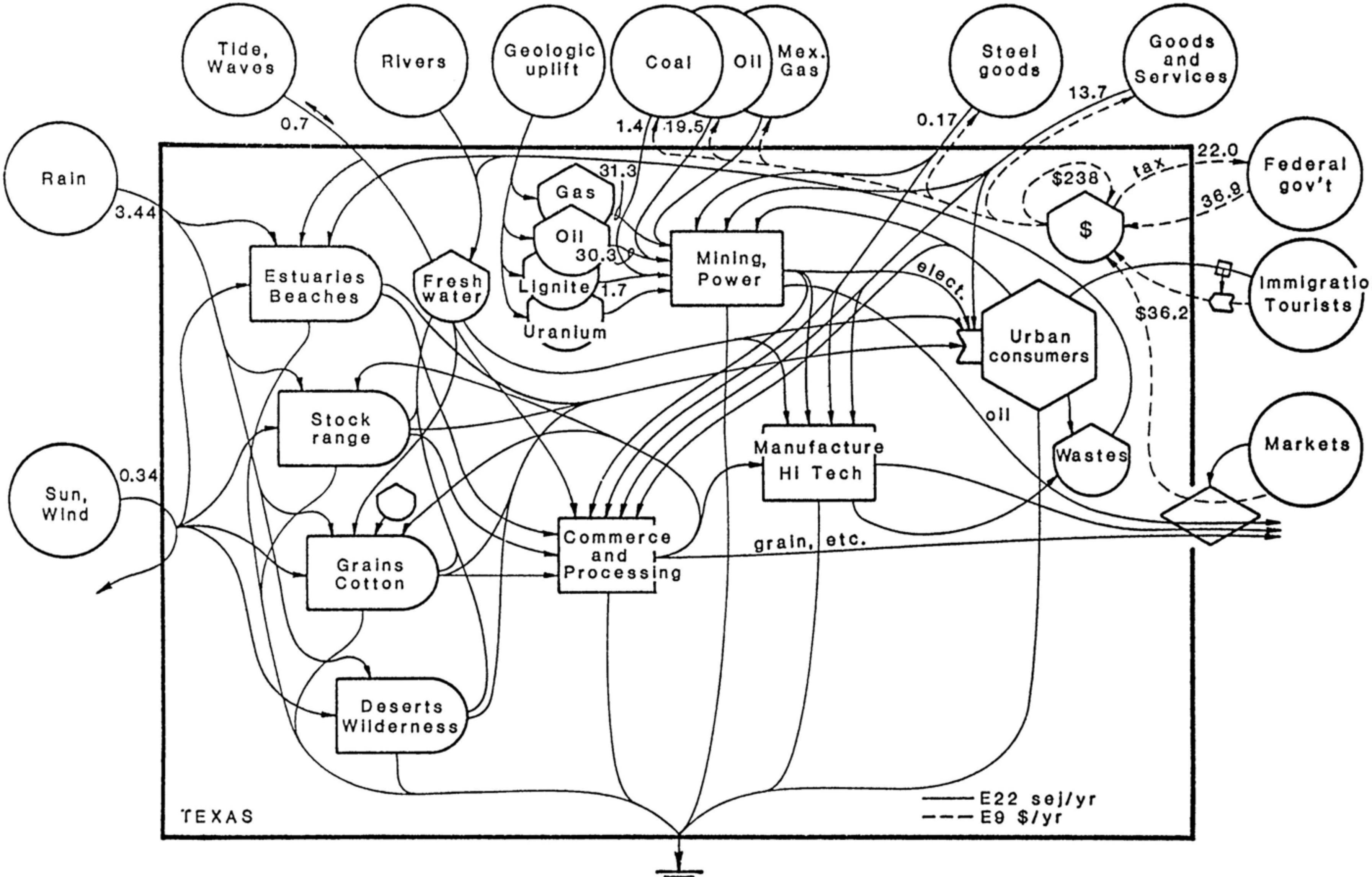
Of the total emergy use within the economy, 6.4 percent (4.1 E22 solar emjoules per year) comes from renewable resources. Likewise, 76.8 percent is based upon nonrenewable resources, and 16.8 percent comes from imported goods and services. Of the total fuels that pass through the Texas economy, 17.8 percent are from out-of-state, and 46 percent are exported to other intermediate or final destinations. Although less than was the case in the past, the state of Texas is still a net exporter of fuels.

In emergy terms, the Texas economy exports 1.6 times the amount it receives from all imports. Most of its exports (77 percent) are represented by fuel emergy, although that fuel export is 54 percent balanced by the import of fuel emergy. In addition to exporting emergy, Texas exports dollars, as the state maintains a net trade deficit.

As can be seen from the diagrams, the dollars paid for imported goods and services represent about 26 percent of the gross state product of $238 billion. The cost of imported goods and services and fuels represent about 35 percent of the state's gross state product if we omit the cost of fuels that without being consumed.

Figure 4.1

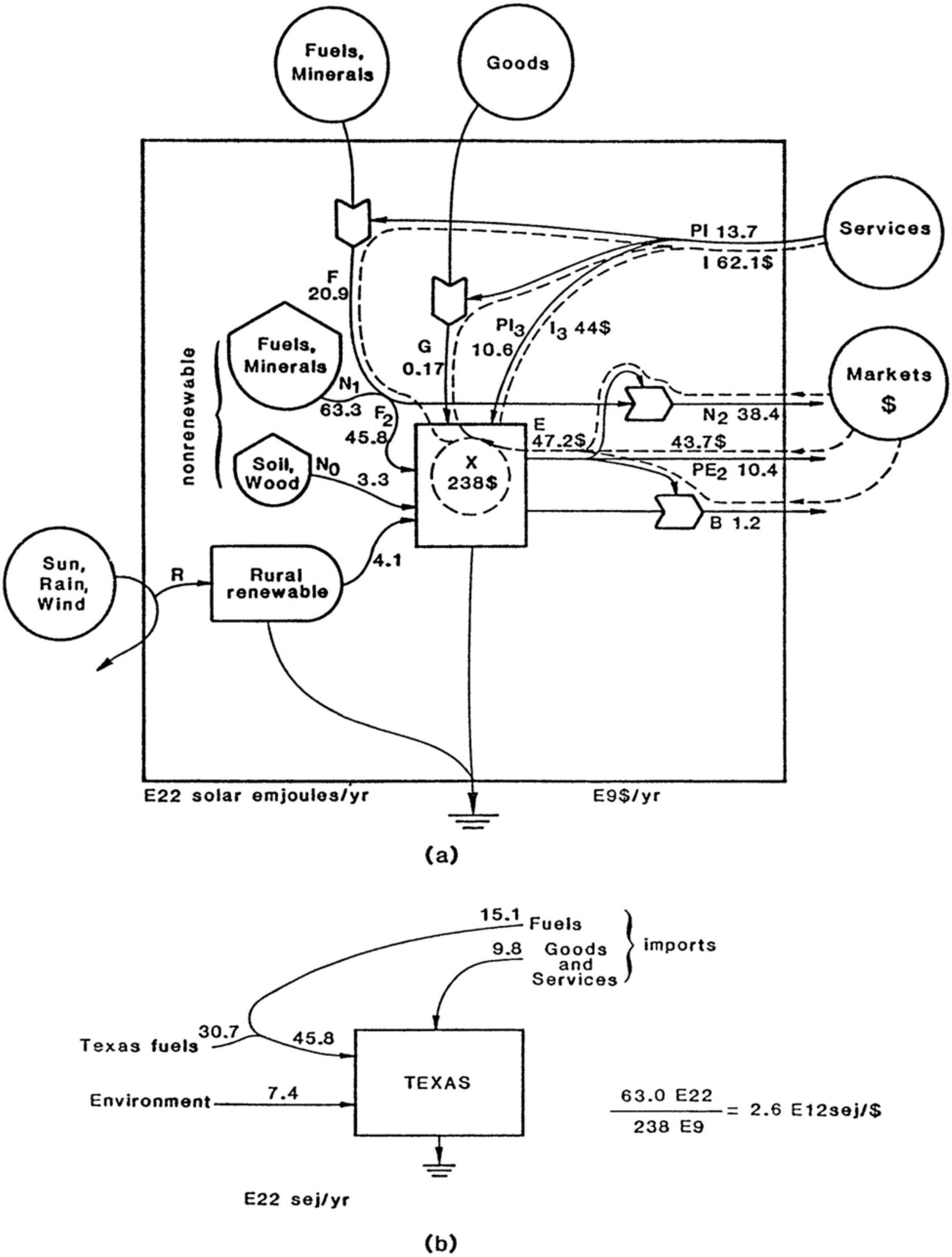
Energy Systems Diagram of Texas



Note: For energy systems symbols, see figure 2.1. Storage symbols contain numerical values of stored emergy; dollar flows are dashed lines; annual flows of emergy are written on solid line pathways; units of solar emergy are E22 solar emjoules; units of money are E9 dollars (billion dollars).

Figure 4.2

Summary Diagrams of the Emergy Basis of the Texas System



Note: (a) Main flows across boundaries; (b) aggregated summary of the resource ...y.

Table 4.1

Macroeconomic Value of Inputs to the Texas Economy in 1983.

Item	Billion $ per year
RENEWABLE RESOURCES	
Rain, chemical potential energy	14.3
Rain, geopotential energy	8.46
Geologic cycle	8.3
Wind, kinetic energy	5.2
Waves	2.46
Direct sunlight	1.42
Hydroelectricity	0.75
Irrigation water	0.50
Tide	0.42
Hurricanes	0.10
IMPORTS	
Net immigration	106.3
Crude oil	81.0
Goods and services	62.1
Tourist dollars	28.0
Iron and Steel products	0.71
Bauxite	0.58
NONRENEWABLE SOURCES WITHIN TEXAS	
Natural gas use	130.6
Oil produced and used in Texas	118.1
Electricity use	71.2
Soil loss as part of use	13.7
Coal and lignite use	13.6

Note: For details of calculations, see appendix 9. Some of these are by-products of common sources and therefore should not be added.

The resource reserves stored in Texas are given in table 4.2. Details of calculations are given in appendix 10. By dividing the storages by present rates of use, the years of supply were found. Fuel reserves will be used up in about 9 to 14 years.

Table 4.2

Macroeconomic Value of Storages in Texas in 1983.

Item	$ (billions)	Years remaining *
Topsoil	2,593	189
Water	18	36
Economic assets	4,600	20
Lignite coal	187	14
Petroleum	1,466	12
Natural gas	1,182	9

Note: For details of calculations, see appendix 10.

* Storage divided by 1983 use rate equals turnover time.

INDICES AND INTERPRETATIONS

The ratio of total emergy used to dollars in circulation in the Texas economy is about 2.7 E12 solar emjoules per 1983 dollar. This represents the relative contribution of the free environmental factors to the economy, relative to the ratio of other states, or other countries. The emergy per dollar ratio for the U.S. is about 2.4 E12 sej/dollar. This indicates that Texas is less "developed" than the U.S. economy generally, and is an exporter of raw products (emergy) as has already been noted. It indicated also that urbanized centers trading with Texas will tend to receive an overall advantage or subsidy. (Table 4.3 presents this and other selected indices calculated from the Texas analysis.)

Emergy use per person, on the other hand, and emergy use per area are slightly higher than the U.S. average, indicating the high standard of living of Texas. The emergy consumed per person is much higher than for most of the world.

In dollar terms, the annual transfer payments to Texas from the federal government ($36.9 billion) are greater than the taxes paid by Texas to the federal government ($22 billion). However, the macroeconomic value contributed by Texas to the U.S. in the emergy value of its fuels exported alone represents a net subsidy of the larger economy of $72.9 billion annually (1). If it were possible for the state to productively consume this fuel resource and export finished products, it would increase the gross state product about 25 percent.

Because of the legislative power of the federal government, Texas is not able to maximize the use of its own fuels towards its own economic prosperity. This is in the nature of systems because, as the "Maximum Emergy Principle" discussed in chapter 2 predicts, larger systems prevail in distributing resource use in order to maximize rates of consumption over the larger realm. By contributing to the larger system, Texas does receive emergy value back in terms of defense protection abroad, technology availability, immigration of trained people, and so on.

Table 4.3

Macroeconomic Characteristics of the Texas Economy in 1983.

Item	$ (billions)	
Sources		
Renewable sources	16	
Imports	118	
Nonrenewable source used	256	
Total	390	
Exports		
Services	47	
Natural gas	42	
Petroleum	104	
Hi tech products	19	
Electricity	3	
Foreign sales of grains	3	
Total	218	
Emergy Import/Export ratio		0.60
Indigenous emergy fraction		0.79
Indigenous and renewable fraction		0.06

Note: For details of calculations of emergy and macroeconomic equivalents, see appendices 11-13.

PETROLEUM

Response to a Drop in World Fuel Prices

A drop in world fuel price decreases the dollars received by Texas for the net export of fuels. However, it also increases the net emergy yield ratio for fuel consumers and stimulates the larger economy and its demand for fuels. Increased economic activity by the larger system may even have a greater beneficial impact within Texas than the negative impact from loss of direct income from fuels.

In the short range, the change in cross-boundary state income due to reducing fuel price by one-half is $5.6 billion per year (2). This loss represents the reduced ability to purchase goods and services from outside the state's economy. This is a 2.1 percent decrease in the total emergy, and thus in the total economy (3).

Because much of Texas fuel production has a lower net emergy (greater production cost) than foreign sources, the Texas production tends to be less competitive and therefore to decline in periods of oversupply as is currently being experienced. Thus, the sales of Texas-produced fuels will be even less than the decrease in price would suggest, and the economic impact will be greater. If Texas were unable to produce a net export of fuels there would be about a 4 percent decrease in the overall economy.

It should be noted that by arresting use of indigenous fuels and substituting more imported fuels, indigenous reserves theoretically are conserved and held for later. Holding back reserves strengthens later economies, and helps keep foreign oil prices from rising too high in later economies. A consequence of shifting fuel use to foreign sources is increasing the total oil saved for later use within Texas or to be sold at higher prices than today's. The macroeconomic value that would be preserved by a complete switch to imported fuels and that would be available for generating gross product in later years to support the Texas economy, is $127 billion (1986 dollars) each year.

If resource shortages limit further growth, there is a strategic advantage to saving commodities rather than acquiring money for reinvestment. In other words, present versus future resource use has a negative discount rate during a declining economy.

The cost of importing fuels to Texas to replace indigenous production used by the economy would be about $22 billion annually for services (jobs) provided outside of Texas, although it would provide a net emergy input to the economy of $105 billion each year. The state and the U.S. in deciding how to respond to oil price declines must balance not only this loss of service sector income, but also the potential loss of production capacity and the vulnerability this entails for the economy. Because net emergy ratios for imported fuels may exceed ratios for indigenous production, policymakers must weigh these considerations against the natural tendency toward dependency on foreign supplies. Unfortunately use of trade tariffs as a means to limit imports reduces the net emergy of fuels used in the economy, therefore having an overall dampening affect.

Effects of an Oil Embargo or Increase in Oil Prices

The oil price jumps following 1973 dampened the economic activity of the entire U.S., including Texas. They occurred, however, at a time when the proportion of the Texas economy represented by oil operations was larger than it is today. At the time a larger portion of the economy benefited by the direct income created by the higher prices. This factor left Texas in better shape than the average of the U.S. The price rose so sharply that large oil investments which stimulated the economy were attracted to Texas. Price regulations on natural gas gave it a high net emergy to consumers and maintained a high demand for gas. The combination of effects was a significant stimulus for the Texas economy.

Since 1973, however, conditions have been changing, as has been noted. When the current overstock of oil has been used and prices rise again, the Texas economy, like that of the U.S. as a whole, may be inhibited by higher fuel cost as much as it is stimulated by the direct income gained. Some marginal production that is currently being abandoned may not be recoverable using known technology; therefore total oil production may be permanently reduced. Although with rising prices Texas would again enjoy a relatively better position than nonproducing states, its growing diversity and growing population suggest that only a modest recovery is probable. A general leveling and downturn in the total emergy use and total gross product could possibly follow.

Taxes or Import Charges on Oil

A state tax on basic energy, such as a tax on crude oil, has a negative amplifier effect due to the high net emergy yield ratio of oil. A tax of $5 when oil is $21 per barrel reduces the main basis of the economy (net emergy contribution from oil) by one-fifth. For Texas, the net economic loss is the total of the emergy of fuels not used by the economy due to the higher prices, less the income created from the tax applied to imports. The net loss would be $27 billion per year (4) assuming the same amount of money is available to purchase our exports. A federal tax on oil production and imports would have a greater negative effect on the Texas economy.

Creation of a $5 per barrel tariff on imported oil alone would generate roughly $3 billion in revenues. This would effect a 19 percent reduction in the use of imported fuels by the Texas economy and thereby create a net loss of emergy to the system that would amount to $14.7 billion, representing a 4.9 to 1 negative amplifier. Assuming that domestic prices rise to equal the cost of imported fuels plus the tariff, the total loss would now be $24 billion to the Texas economy. This represents a dampening affect of 8 to 1. (5)

AGRICULTURE

Agriculture's role in the economy is analogous to oil refining, as it organizes basic energy sources into useful products for consumption. Agriculture products require a good deal of human services and fuels input in our present economy, but they also embody a significant contribution from continuous, renewable solar energy, rain, wind, and the stored energy of the soil. Because agriculture, therefore, has a high emergy contribution to the economy compared to the value received in market prices, its effect on the Texas economy is much greater than would be inferred from the dollars paid for its products. In 1983, receipts from farm and ranch marketing were about $9 billion, 3.8 percent of the state's gross state product. However, the contribution on an emergy basis is about 13 percent, giving the economy a stimulus about 3.5 times more than its dollar value. Even with improved national farm policies, Texas (and U.S.) agriculture can improve its net contribution to the economy by reducing input costs and substituting labor and land for fuel-based inputs. Optimizing output for agriculture is discussed in more detail in Chapter 7.

TRANSPORTATION

Transportation consumes 22.5 percent of the state's total emergy budget (6), whereas the percentage of the gross state product that it represents in dollar terms is only about 3.5 percent. The primary method of transportation in Texas is by use of highways (see the emergy analysis of transportation in chapter 6).

Highway transportation, by facilitating vehicle access, is a principal means by which emergy rich resources (fuels, asphalt, cement, steel) are applied to the growth of an economy. In other words, transportation contributes net emergy to the economy, thus stimulating other aspects of the economy during a growth period. The net emergy yield of transportation investments was calculated as 17.6, which accounts for its historic strength in the state budget (7).

During a period of economizing and increasing efficiency, necessitated by declining per capita emergy availability, actions that extend the life of roads and reduce maintenance costs make a positive contribution to the economy. Reducing the weight of cars by one-half, for example, would involve a net savings of about 8 percent of the state's total emergy (8). Such conservation would increase the competitive position of Texas products in outside markets by 8 percent. The potential savings, representing about $19 billion annually, which could be available for stimulating other activities in the economy, is greater than the impact of the oil price drop discussed earlier.

SIMULATION OF A TEXAS MINIMODEL

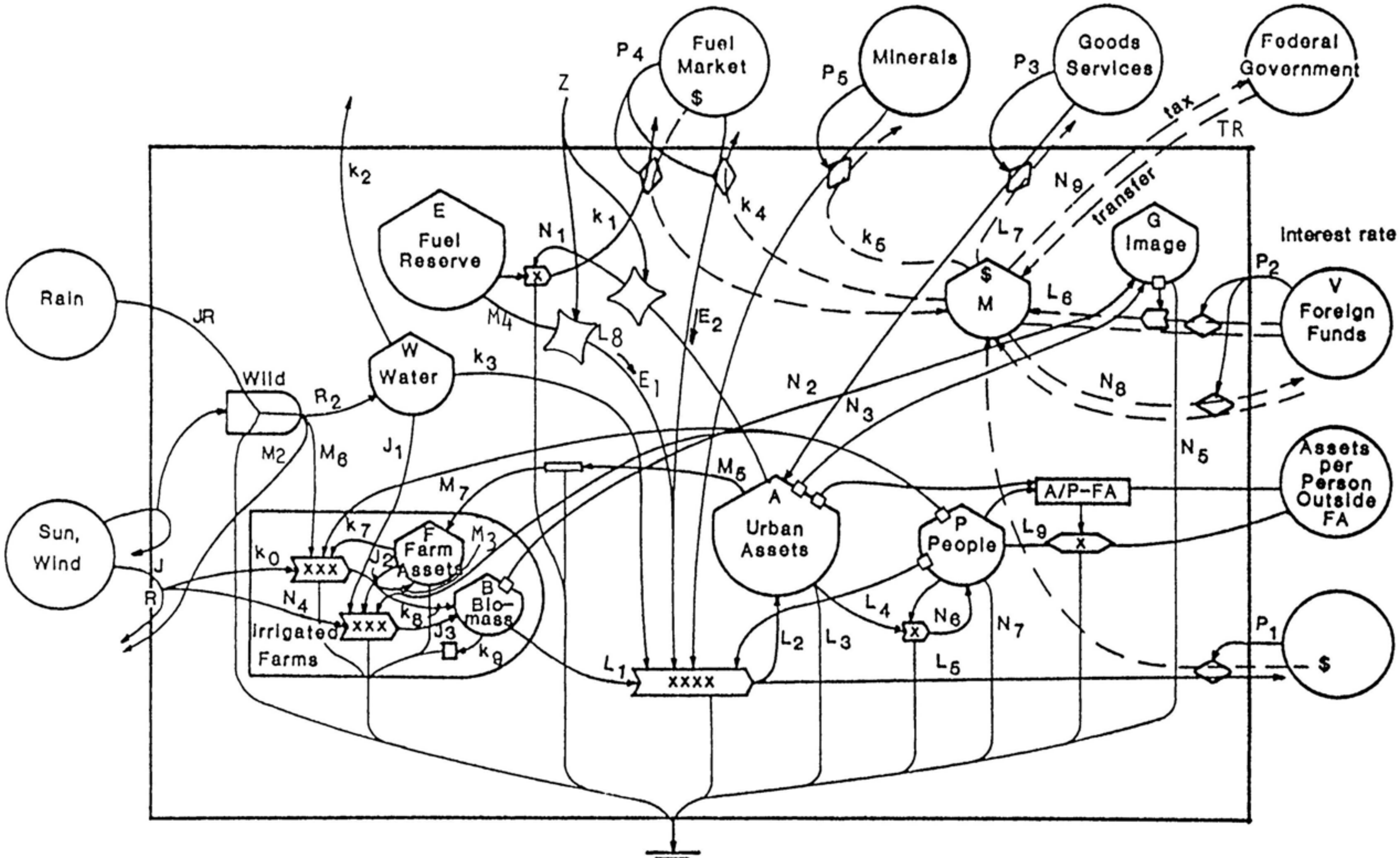
Computer simulation of overview models shows how main factors affect an economy. A simulation shows what would happen to the economy given various conditions. A microcomputer simulation model of Texas is given in figure 4.3. Notice it is an aggregated version of the diagram of the Texas system in figure 4.1. It was calibrated with emergy data (appendix 12). The model shows urban assets growing with inputs from agriculture, use of fuel, and use of goods and services bought with income from sales of fuel and other products and services. Population grows from reproduction and from immigrations attracted in proportion to the assets per person in Texas. Both agriculture and urban growth deplete an already limited supply of water.

The first simulation of the model (figure 4.4a) in Texas, omits oil development and oil sales. It shows the growth that takes place based only on an agrarian basis. Something like this might have occured if oil had never been discovered. After a period of transition, an economy results that supports the same population as now but at about half the present standard of living.

The simulation in figure 4.4b starts oil development use and sales 60 years after the program starts. Availability of oil for import at $15 per barrel is held constant. During explosive growth of urban assets and population based on Texas oil, development is restrained by water limitations and the system develops a steady state (an equilibrium) with the present population at about half the present standard of living.

Figure 4.3

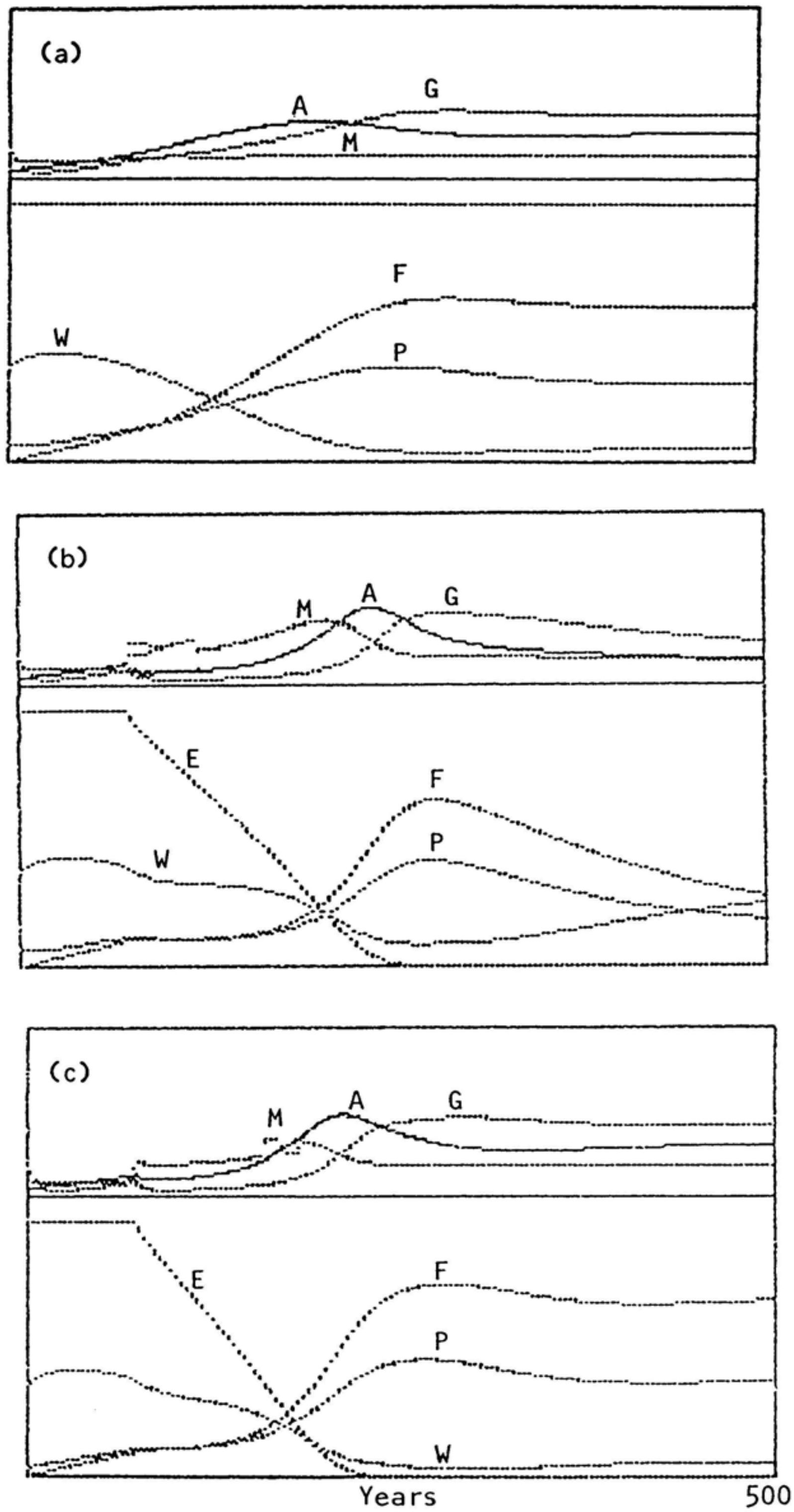
Systems Diagram of the Simulation Model of Texas



Note: Letters used are for mathematical equations of the model listed and calibrated in appendices 14-16.

Figure 4.4

Graphs from Simulation of the Model in Figure 4.3 where Letters are Identified



Note: (a) Agrarian economy without oil development; (b) oil development started after 60 years with oil price rising about 1 percent per year; (c) simulation as in figure 4.4b but with a sequence of foreign oil prices as in the past and rising about 1 percent per year for future years.

The simulation in figure 4.4c also starts oil development after 60 years, but the prices were changed at different times, simulating recent history. Then the oil import price was increased about 1.0 percent per year into the future. After an oil-based growth period, an agrarian-based steady state was reached supporting 15 million people at half the present standard of living. The simulations suggest a sustainable role for agriculture after the main period of fossil fuel use.

ENERGY RESOURCES FOR URBAN USE

Much of the production from the resources of the economy converge on the cities where most of the human consumers live. The way in which the environmental resources contribute to a city is shown by the pathways from the left and top of the diagram in figure 4.5. As more emergy is contributed from the local surroundings, more value goes into the city economy, keeping its products economical, increasing income, and thus increasing the amount of additional resources that can be purchased. Notice in figure 4.5 the fuels, goods, services, and other resources from the right side of the diagram. Environmental protection helps enrich the city economy by maximizing the emergy inputs locally as well as those that can be imported.

Many of the opportunities for energy conservation occur in cities, especially the ability to organize transportation in a natural hierarchy. The closer activities are to the center of the city, the more cost there is in maintaining them. Activities that are economical in the center of a city are those for which high economic and population density is useful, such as government and communication among cooperating people. Many other activities are more competitive or efficient in low-density areas where more environmental resources can be used. Some industries need the environmental buffers, cooling winds, and lower taxes of areas away from the center.

The ultimate size of a city depends on its area of support, including inputs from smaller cities that become organized to support the city and receive services from it. For example, San Antonio, by serving large areas of Mexico, develops a larger base for its growth than the Texas area around the city. When fuel prices rise again, resources to support many cities will decrease, further growth of the cities will cease, and some will decrease in size. Good policy requires plans now that recognize these possibilities in the next decades.

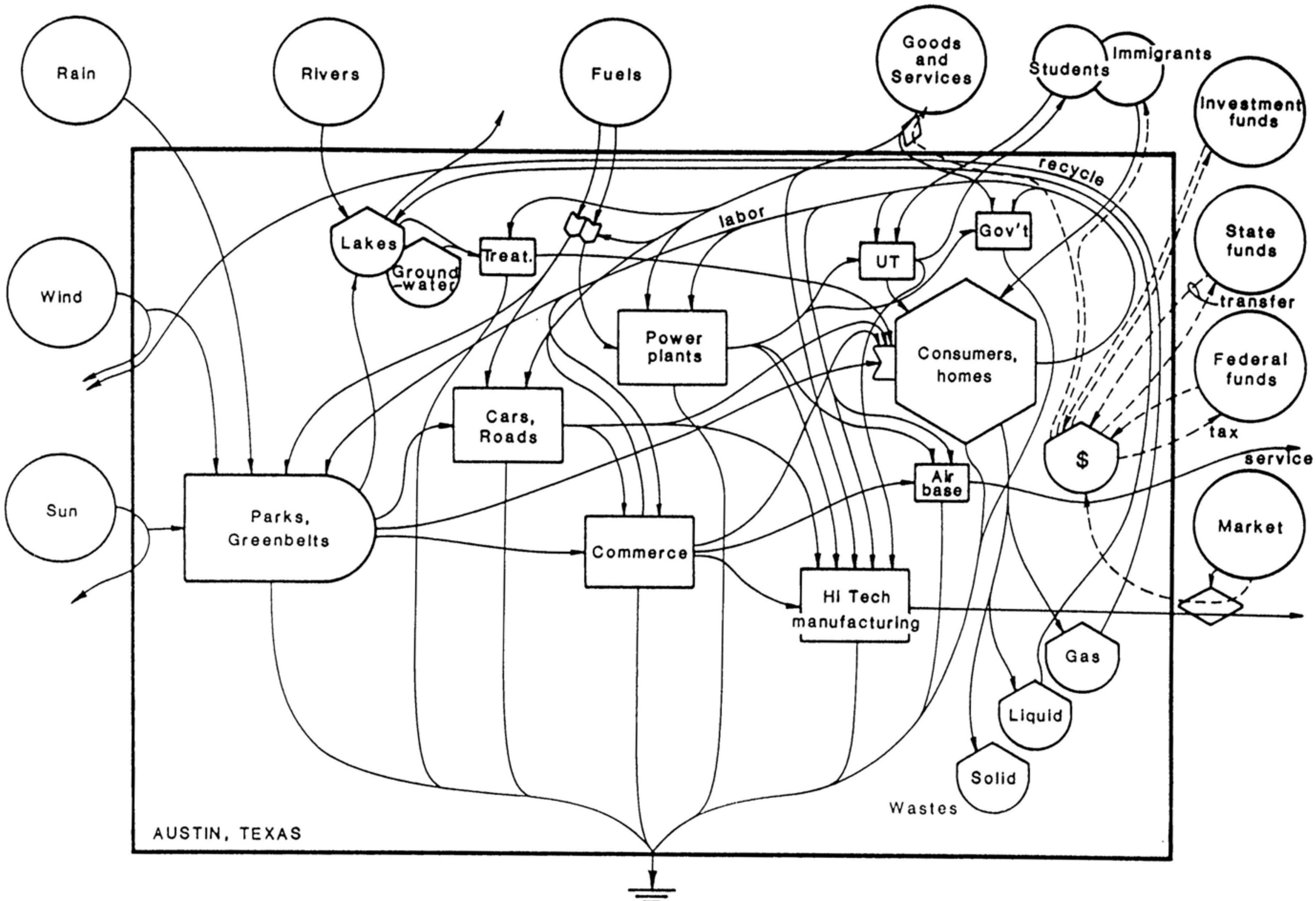
SOLID WASTES

The total emergy in solid wastes that are buried and otherwise lost to the economy is $27 billion annually. In addition, the accumulation of concentrated waste in small pockets everywhere is creating a negative impact on the economy. Associated with waste disposal are unnecessary expenditures for high-cost processing, such as tertiary sewage treatment. (The costs of waste disposal are discussed in greater detail in chapter 6.)

If appropriately recycled, partly by reuse within the economy and partly by dispersal for appropriate reincorporation into environmental systems, the so-called "wastes" become by-product resources. The contribution to the total

Figure 4.5

Energy Systems Diagram of Austin, Texas



Texas economy in savings and in increased resource availablity could be as high as $9 billion per year, a contribution of nearly 4 percent to the state economy.

WATER AND MARINE RESOURCES

The bays, beaches, and coastal shelves of Texas make a renewable emergy contribution to the economy too. Their sunlight, rains, tides, and waves combine with the economy to absorb and recycle wastes and to generate fisheries, tourism, and other products and services. These resources are 12.4 percent of the economy of the coastal counties and 2.8 percent of the state's economy (9). Using the investment ratio principle (from chapter 2), the purchased emergy that can be attracted by use of these resources is 7 times larger than their direct environmental input. The emergy analysis of the coastal marine resources in chapter 5 indicates that the coastal areas of Texas still have room to grow.

The emergy in the water of rivers reaching the estuaries is larger than that in the rain on the coastal counties. The question of whether or not to divert river water upstream to other uses is often controversial. Sometimes water is diverted based on the perceived dollar value of its proposed urban or agricultural use without subtracting the loss of economic value that would have been generated in the coastal area. Chapter 5 discusses the value of water to the economy in its various uses. Marine use of water could be preferable to a wasteful use upstream.

RESOURCES EXCHANGED ACROSS THE TEXAS-MEXICO BORDER

As is the case in Texas, oil and gas production is important to Mexico. A significant amount of production is consumed within its borders, and if its oil and gas production were to cease, the standard of living in Mexico would be reduced to only 5 percent of its current level. In addition, a large portion of its resources are exported, enriching other economies more than Mexico receives in exchange. In fact, Mexico supplies Texas and the U.S. with more net emergy than it receives from us for the same reason Texas supplies more emergy to the U.S. than it receives in payments. Mexico supplies raw products, fuels, and goods and services that have more emergy, or a higher emergy-per-dollar ratio (see table 4.4).

Some indices calculated from data in table 4.5 indicate that the emergy consumption per person, an indicator of quality of life, is much higher in Texas than in Mexico. Therefore, it is a driving impetus for immigration and migrant labor. On the other hand, the emergy-per-dollar ratio for Mexico is not sufficiently high to classify Mexico as an undeveloped country. The image Americans have of Mexico as a rural country is already very out-of-date. The population is, in fact, 67 percent urban.

Net immigration into Texas from Mexico is estimated at almost 0.5 million people per year. The emergy contribution (in terms of the inflow of educated adults to the economy) is substantial, but such immigration during a period of a leveling or declining resource base reduces the standard of living in general.

Table 4.4

Macroeconomic Evaluation of Exchanges between Texas and Mexico.

Annual macroeconomic exchanges	$/yr (billions)
Mexico to Texas (fuel, trade, immigrants, drugs, agr. produce)	74.2
Texas to Mexico (trade, finance)	34.6
Advantage to Texas	39.6

Note: For details see appendix 8.

Mexican policy in recent years has been to devalue its peso, as much as ten-fold, in order to improve foreign exchange. This was not the best policy for a country exporting raw products such as oil. Reducing the currency value reduces the net emergy of the foreign exchange. Reducing the peso reduced the ability of the Mexican economy to be stimulated by its own oil and in fact stimulated the Texas economy.

The development of twin industries along the Rio Grande River now involves a substantial dollar income to Mexico. These plants are built in order to allow much of the labor to be performed in Mexico at lower wage rates, with the final products returning to the U.S. Because the emergy per dollar ratio for Mexico is 16 percent higher than for Texas, the Mexican wage can be slightly lower than in the U.S. and still be equitable. Wage differences are much larger than this, however, and so represent a net emergy benefit to Texas. At the same time, because the U.S. standard of living is making U.S. products less competitive, this relationship with Mexico is helping the regional economy balance, while reducing some of the cross-border gap in emergy per person.

Peaceful coexistance for bordering countries may lie in equalizing emergy exchanged. Foreign aid is one action that tends to help equalize exchanges between emergy-benefiting developed countries and less developed emergy-supplying countries. The capital investment from the U.S. in twin plants in Mexico may help reduce the emergy exchange imbalance and preserve our relationship with Mexico.

Table 4.5

Comparisons between Texas, U.S.A., and Mexico, 1983.

Item	Units	Mexico[1]	Texas[2]	USA[3]
Gross national product	billion $/yr	121.7	238.0	3300.0
Population	million people	72.	15.7	234.
Resource use, emergy/yr	E22 sej/yr	35.	67.4	786.
Emergy/person	E15 sej/person	4.9	43.0	34.0
Emergy/area	E11 sej/m2	1.8	9.6	8.4
Emergy/1983 internat. $	E12 sej/$	2.9	2.6	2.4
Imports/Exports	Ratio	1.6	0.6	1.75
Emergy self-sufficiency	$ indigenous	80.	79.	76.
Indigenous renewables	sej/sej	20.	6.	10.
Purchased/free	sej/sej	2.5	7.5	7.4

[1] Appendix 17

[2] Appendix 13

[3] Appendix 5

POLICY INFERENCES FOR TEXAS

Long-range policies to maximize the vitality of the economic position of Texas and its citizens should be to maximize emergy availability and its efficient use. Policies that are most likely to accomplish this include:

1. Maximize resource availability over time by using imported resources first and saving resident reserves for later, to the extent national security and production capacity considerations will allow.

2. Develop resource conservation by investing in those measures with a higher net emergy saving. These include measures for water conservation, waste recycling, smaller cars, less private car use in cities, less wasteful aircraft competition, etc.

3. Facilitate the reduction of agricultural costs by substitution of labor, land rotation, and water conservation for practices that require high-intensity input of equipment, pesticides, and fertilizer and high interest on loans. An example is small-scale farming using appropriate technology including smaller-sized tractors.

4. As the fuel basis of the cities declines, develop land policies that would distribute people on the land in medium-intensity agriculture (optimizing rather than maximizing production). Land development policy should also recognize the high economic contribution of agriculture and the environment to urban centers.

5. Encourage the reinvestment of Texas dollars in Mexico in order to increase the emergy-per-person ratio for that country, help it develop its own resources within its borders, and thereby slow immigration and the decline of the Texas standard of living.

ENDNOTES

(1) Macroeconomic dollars in net exported fuel:
(38.4 E22 sej/y - 20.9 E22 sej/y) = 17.5 E22 sej/y
(17.5 E22 sej/yr)/(2.4 E12 sej/$) = $72.9 E9 $/y
This is equivalent to 33% of the resource base of the Texas economy:
(100 %)(72.9 E9$)/(238 E9$) = 33%
Gain by use in the state:
(100%)(72.9 E9 $ - 11.2 E9 $)/238 E9 $ = 25.9%
See footnote (2).

(2) Dollars lost in short run by reducing oil price by half
Exported fuels (N2 in Table 4.3) = 38.4 E22 sej/yr for which $24.56 E9 was received. Emergy price was:
(24.56 E9)/(38.4 E22 sej/yr) = 6.4 E-14 $/sej
Dollars received for export of emergy:
(17.5 E22 sej/y)(6.4 E-14 $/sej) = 11.2 E9 $/y
If price were half, the dollars received would be equal to:
(0.5)(11.2 E9 $/y) = 5.6 E9 $/y

(3) Percent decrease in emergy of the economy by loss of purchased goods and services:
(100%) (5.6 E9 $/y)(2.4 E12 sej/$)/(63.9 E22 sej/y) = 2.1%

(4) Disadvantage of tax or import charge on oil that raises oil price $5/bbl:
Fraction of oil not used = ($5)/($21/bbl + $5) = 0.19

U.S. economic loss:
(0.19)[(420.2 + 73.1 E22 sej/yr)/(2.4 E12 sej/$ - 20.21 E9)] = 386.7 E9$
(100)(386.7 E9 $)/(3305 E9 $/y) = 11.7%

Texas economic loss from decrease in emergy of imports assuming increase in dollars in exports is balanced by decrease in sales:
(0.19)[(45.8 E22 sej fuel use/y)/(2.7 E12 sej/$) - $27.26 E9] = $27.1 E9/y
(100)(27.1 E9 $/y)/238 E9 $/y) = 11.4%

(5) Revenue for $5/barrel on 585.6 E6 bbl/y:
($5/bbl)(585.6 E6 bbl/y) = 2.9 E9 $/y

Macroeconomic value lost per unit revenue:
($23 E9 $/y)/2.9 E9 $/y = 8.

(6) From Lyu, Wernhuar. "Emergy Analysis of Highway Transportation in Texas." Unpublished student report for Policy Research Project course, The University of Texas at Austin, LBJ School of Public Affairs, 1986, pp. 130-157, and Chapter 7, annual emergy of highway production and maintenance 3.97 E22 sej/y and highway use 11.5 E22 sej/y for a total of 15.16 E22 sej/y.
Share of economy: (100)(15.16 E22)/(67.4 E22) = 22.5%

3.5 percent of gross state product identified with transportation by Plaut, T.R., S.M. Tully, and P.J. Henaff. Texas Economic Outlook: Long-term Forecasts. Austin: Bureau of Business Research, University of Texas at Austin. 1984.

(7) Net emergy Yield Ratio of Transportation using data of Lyu (Note # 6) in
Figure 6.3 = (Total emergy contributions)/(feedbacks of service)
For highways: (3.97 E22 sej/y)/(0.43 E22 sej/y) = 9.2
For use of Highways: (15.17 E22 sej/y)/(0.86 E22 sej) = 17.6

(8) Estimate the emergy savings of half-sized vehicles and half the fuel:
(1/2)(1.68 E22 + 9.31 sej/y) = 5.49 E22 sej/y
plus savings in highway replacement and maintenance.
Percent savings: (100)(5.49 E22)/(67.4 E22) = 8.2%

(9) Macroecoonomic value of the emergy contribution of marine resources
from Table 5.2 (not counting gas and oil):
(3.7 +3.5 + 2.7 + 2.7 + 0.5) = 13.1 E9 $/y.

Total emergy for coastal zone, 15.2 E22 sej/y. Percent of coastal economy due to renewable marine resources:
(100) (1.89 E22)/(15.2 E22) = 12.4 %
Percent of total state emergy flow: (100)(1.89 E22)/(67.4 E22) = 2.8%

Chapter 5

THE ROLE OF WATER IN THE TEXAS ECONOMY

With half of its area in an arid climate, the carrying capacity of the Texas economy is limited in places by water supply and quality. Criteria are needed to choose between alternative uses. To maximize economic vitality, public policy should manage water to generate the largest macroeconomic value. As defined in chapter 2, the macroeconomic value of a quantity of water is the number of dollars in the economy that depend on this water directly or indirectly.

The economic value of water is sometimes defined as the price people are willing to pay, which depends on cost, supply, and demand. However, water contributes to an economy most when it is abundant, it is taken for granted, and little money is paid for it. Therefore, the contribution of water to the gross economic product may be many times greater than its cost. In this study emergy evaluation was used to determine the macroeconomic dollar values of water to the economy including wastewater and marine water. These values were used to develop suggestions for water policies.

WATER EVALUATION

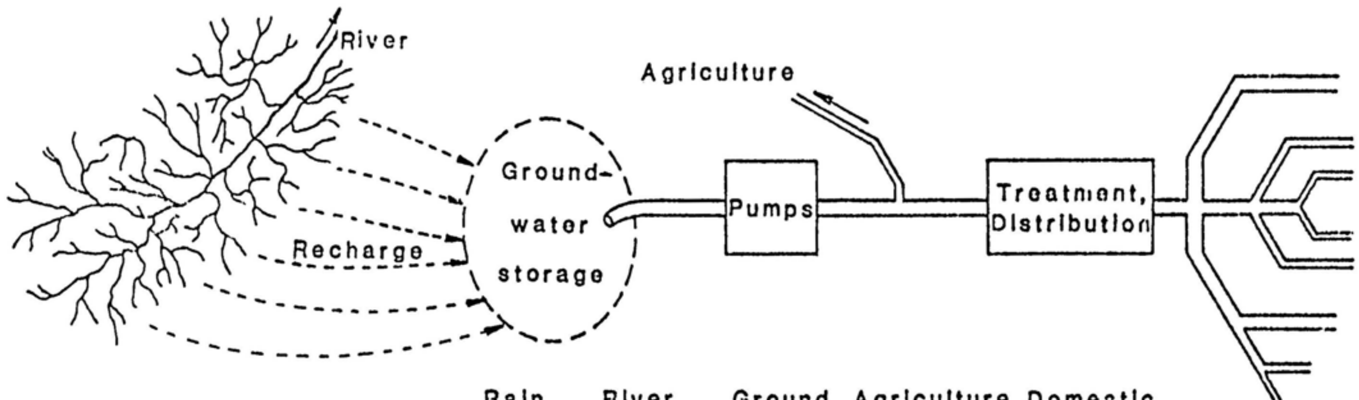
Water evaluation begins with the dollar value of rain as it flows into the ground and is later processed for agricultural and urban use. Figure 5.1 lists two dollar values for rain, runoff, recharge into groundwaters, and pumping for agriculture and cities. It is based on appendix 22. The macroeconomic value (macroeconomic \$/m3, dollars of gross product estimated from emergy) is given first; the regular economic value (microeconomic \$/m3, the price people will pay) is given below. The diagram shows costs and macroeconomic values increasing as one cubic meter of water is concentrated. Nature gathers and concentrates part of the rainwater in rivers and in groundwater storage. In the process, the water helps build vegetation and soil, enrich watersheds, and stimulate agricultural production. Some water goes to city consumers. Emergy and macroeconomic dollar values are given per one cubic meter of water finally consumed.

In figure 5.1, 1.4 percent of rainwater goes into direct economic use, either in agriculture or in urban residential use. As the water is concentrated, the value of the water per unit becomes greater. For example, a cubic meter of rainwater has \$0.035 macroeconomic value; whereas when water has been concentrated in the aquifer, a cubic meter of the groundwater is worth \$0.09. When the water is used in agriculture, the value of pumps, pipes, electricity, and labor are added to the value of the water. The macroeconomic value of a cubic meter of agricultural irrigation water includes \$0.25 for the water itself and \$0.19 for the electricity and labor, a total macroeconomic value of \$0.44.

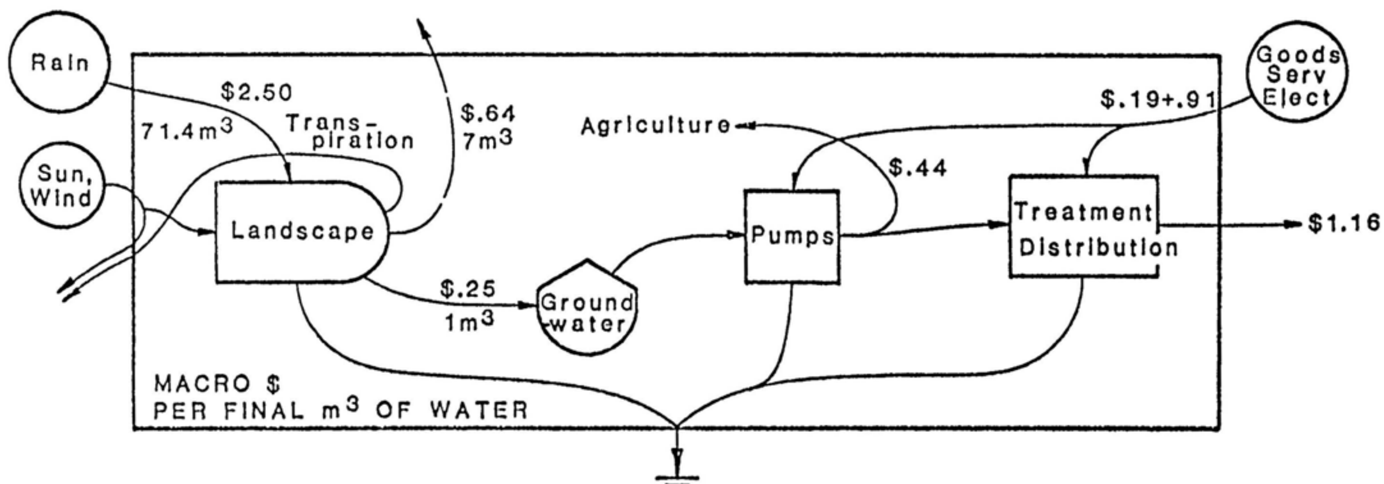
As water is concentrated, the total volume decreases, and the value added from the economic system increases. By its concentration, location, and sanitary state, water gains greater utility as inferred by its greater emergy per unit. The diagram also shows the increasing work of collecting and transporting the water first by nature and then by man-made pipes and pumps. Note that the measure of this work, the transformity (solar emergy per unit energy), increases 40 times as rain is diverted to urban residential use.

Figure 5.1

Stages in Water Processing and Use
Starting with Rain on the Left and Urban Use on the Right



	Rain	River	Ground	Agriculture	Domestic
Transformity sej/J:	15,444.	41,068	110,314.	255,242.	665,714.
Macro $/m3:	$.035	$.09	$.25	$.44	$1.16
Micro $/m3:	0	0	0	$.04	$0.79



Note: Macroeconomic values are compared with market values (microeconomic values). The systems diagram shows the sources of work contributing value.

Compare the macroeconomic value of agricultural water, $0.44 per cubic meter ($1.67/1,000 gallons) with the price paid for it by the farmer, $0.04 per cubic meter ($0.15/1,000 gallons). The macroeconomic dollar value is seen to be more than 10 times greater than its cost. The value in the water is contributed to the crops, giving them higher macroeconomic value than is paid for them. Society, by receiving cheap food produced by irrigation, is getting 10 times more economical use from the water than the farmer pays for pumping it.

After additional electricity, goods, and services are added to the water, which is further concentrated, treated and distributed to urban consumers, its macroeconomic value ($4.39) is still $1.39 more than the money spent ($3.00). The water is a net emergy contributor, stimulating the economy of the consumers more than is paid for it. Because water must be pumped from aquifers deep underground in the arid regions of the state, more emergy from the economy is required to obtain this water than is required to obtain water in areas with heavier rainfall. However, as groundwater levels are lowered by irrigation pumping and as electricity becomes more expensive, irrigation costs increase. Eventually the water no longer contributes a net emergy.

Water Reserves

Water stored in reservoirs and in other groundwater storage areas is included in the summary of resource reserves in table 4.2. Of the $18 billion macroeconomic value in stored water, 1 percent is in reservoirs. Irrigation uses about 2 percent of the storage per year, which may be higher than the recharge rate.

Evaporation from open water reservoirs ranges from 90 inches per year in West Texas to 10 inches per year in East Texas (1). On the other hand, evapotranspiration of arid lands is much less. Most natural landscapes preserve water by storing it underground in the sands under arroyos or in deep canyons. Much water can be saved by returning to this pattern where possible. Dams and reservoirs provide easier control and seasonal stability, but at great cost. Reinjecting waters into groundwater reservoirs is a better way. These reservoirs are composed of gravel and sand, which have porosities of 15 to 40 percent.

Water-Pumping Windmills

Windmills were important in Texas because they provided water for stock located far from human habitation. Properly placed, the windmills were used to keep cattle distributed over the range. Later many windmills were replaced with fuel or electric pumps because these sources of energy were cheap.

Wind is an abundant, but a dilute, form of energy. The average wind velocity in Texas is 9.7 miles per hour (2). Available energy in wind increases as a cube of the velocity. Therefore, above-average winds do much more work than those below average.

Small windmills are still used extensively on the plains. A summary of an emergy analysis is given in table 5.1 for a commercial mill in current use. The summary is based on details given in appendix 19. There is no net emergy

Table 5.1

Emergy Characteristics of a Texas Windmill Waterpump
and an Electric Pump

Item		Sej/year (trillions)	
WINDMILL PUMPING			
Wind used per year		7	
Equipment prorated over its life		187	
Pumping work delivered per year		15	
Water delivered		350	
ELECTRIC PUMPING			
Electricity used per year		367	
Services required		177	
Total		544	
Net emergy benefit including electricity saved	350 + (544-188) =	706	
Net macroeconomic contribution			$271/yr
Net emergy yield ratios			
of wind pumping	15/188 = 0.08		
of wind-pumped water	350/188 = 1.86		
of electric-pumped water	350/544 = 0.64		

Note: The windmill is 6 feet in diameter on a 21-foot tower. For details see appendix 19.

yield; it draws more from the economy than it gives. The wind is not a substitute for fuels as a primary energy source. However, the ratio between the input from the economy to that of the water and wind from nature is 1.2/1. This ratio is less than the state average of 7, indicating that this kind of small, water-pumping mill is economical. It is a good investment because the emergy of the water obtained is higher than the emergy return on most investments.

An alternative to using the windmill is use of an electric pump, which is also evaluated in table 5.1. The direct dollar costs to pump the same amount of water are almost the same. However, the investment ratio for using the electric pump is 3 times higher than for using the windmill. The electric alternative takes 3 times more emergy from the economy that could be used to produce something else. With rising fuel costs, returning to the use of small windmills should be considered. A program to subsidize windmills could make the economy more competitive by saving electricity for higher quality uses.

Desalination of Sea Water

The large amount of energy required to remove salt from seawater limits practical use of desalination. In the 1970's extensive research was funded, and desalination plants were tried around the world. Most plants were abandoned because activities using such expensive water could not compete economically with those in areas receiving rain.

Nontechnologists sometimes imagine that unlimited energy from nuclear fusion will make the use of desalination practical and provide unlimited water for desert areas. Fusion, however, is too hot (50 million degrees compared to 1,000 degrees in an ordinary power plant) to yield a positive net emergy. As the temperature of the core of a power plant increases, the amount of emergy needed to develop, contain, and then cool down that temperature for use in the cool biosphere increases.

Water Aqueducts and Oil Pipes

After it has been collected and stored, water has a macroeconomic value of \$0.25/m3 (figure 5.1). Oil has a macroeconomic value of \$735/m3 (3). It has been economical to transport oil in pipelines because of the highly concentrated value in oil compared to the more dilute value of water. However, when the oil and gas reserves cost more to drill than they yield, the network of oil and gas pipelines could be reorganized to carry water. The energy needed and expense of pumping water to go uphill from East Texas to West Texas are prohibitive, to move water from East Texas to South Texas through pipelines may be feasible since no change in elevation is involved. Better water distribution would help Texas agriculture. Since the macroeconomic value of the water to the economy is much greater than its price, public expenditures beyond the price paid by water users are justified in processing water.

Water Value in Dry Areas

In dry areas of Texas, where water is scarce, the plant leaves and soils operate at higher salinity than in humid areas. A given amount of water can support greater agricultural productivity in the arid area. Water used in such dry areas carries double the emergy and macroeconomic value. (The technical reason is that the chemical potential energy between fresh water and the leaves that transpire the water is higher than in wet areas; for example 10 joules/gram water instead of 5 joules/gram).

Also, fewer fertilizer nutrients are leached from soil in arid regions. As a result, agricultural production per unit of water is increased, providing that irrigation water is applied directly to plants with a ground-level trickle system, not sprayed into the air where much of it is lost.

River Discharge into Estuaries

The emergy in river water that reaches the estuaries is greater than that in the rain in the coastal counties (see table 5.2). Diverting river water to other uses is controversial. Sometimes water is diverted because of the perceived dollar value of its proposed urban or agricultural use without subtracting the loss of economic value that was generated in its coastal role. The emergy evaluation gives the water the same macroeconomic value wherever it is used, minus the waste involved. Because the vapor pressure of salt water is less than of fresh water, making evaporation slower, the marine use in many cases may be preferable to some wasteful irrigation practices or loss of water from reservoirs.

Table 5.2

Macroeconomic Value of Inputs to the Texas Coastal Zone Shown in Figure 5.5.

Item	$/yr (billions)
RENEWABLE INPUTS	
Direct sunlight	0.3
Rain on land and shelf	3.7
River inflows	3.5
Sediments carried by rivers	2.7
Beach waves	2.7
Tide and sea set	0.5
OIL AND GAS	
Used in the area	52.7
Sold outside	72.6
ECONOMIC USES	
Commercial fishing	0.4
Sports fishing	0.9
IMPORTED GOODS AND SERVICES	5.9

Note: Details of calculations are given in appendix 20. Some items are included in others.

Diverting Water to Cities

As most of the population moved to the cities, great demand for water for industries, households, and ornamental vegetation developed. People in cities were willing to pay much more for water than rural users could pay. Thus, pressures developed to move water away from agricultural to city use. Those using "willingness to pay" as the measure of value to the economy recommended that water go to the highest bidder and thus to the cities.

POLICY IMPLICATIONS OF THE NET EMERGY OF WATER

The high macroeconomic value of irrigation water is an example of the subsidy of the environment to the rest of the economy. Water contributes more emergy to the economy than is used in processing it. In other words, it contributes net emergy. Water usually contributes many more dollars to the gross economic product than is indicated by the processing costs.

Since the present value to the entire economy of agricultural irrigation is 10 times more than its cost, more expenditures are justified for water projects and conservation than will be recovered by water purchases. Additional expenditures for conservation of water in rural areas are likely to have a 10-to-1 amplifier effect. Conservation of water in the city will have less effect, but it can still be a significant stimulus to the economy.

The overall contribution of water to the economy is not measured by what users pay, but by the contribution that the water makes possible in agricultural products as they go through the economy from producer to transporter, wholesaler, retailer, and finally to final consumers (see discussion of figure 5.1). The emergy method of estimating macroeconomic value is the appropriate measure. The price of one acre-foot of agricultural water is $50/acre-foot; the macroeconomic value to the economy is $543/acre-foot. The emergy-based evaluation should be used to maximize economic vitality.

Consider a town that exists solely as an agricultural center in a dry area with irrigated agriculture. In this simple example, moving the water from the farms to the town would eliminate the basis for the town's economy. The emergy of the water is the means for attracting the investments that bring in additional emergy, typically 7 times that of the local resource use. On the other hand, a town whose economy was based on industry using fossil fuels might generate more emergy per unit of water used than agriculture.

Table 5.3

Macroeconomic Values in Wastewater Release into Marshes at Port Aransas, Texas.

Item	$ per year
Sun	1,345
Tidal energy	4,230
Rain	11,300
Waste water	153,694
Services and equipment*	1,366,000

Note: For details see appendix 21.

* Water, transport, delivery, and sewage disposal

WASTEWATER

Wastewater from cities, industries, and agriculture is valuable and often contains useful chemical substances such as fertilizer nutrients (nitrogen, phosphate, and potassium). Since water has high emergy and macroeconomic value, it should be processed so as to contribute to the economy. With care to eliminate toxic substances, most wastewater may be processed for forest or agricultural uses or released to help maintain natural vegetation, soils, and wildlife.

Reuse of wastewater is an example of a general principle: that successfully competing economies do not have wastes, only by-products. In other words, when a use is found for a waste, it becomes a positive contributor to the economy instead of a negative one.

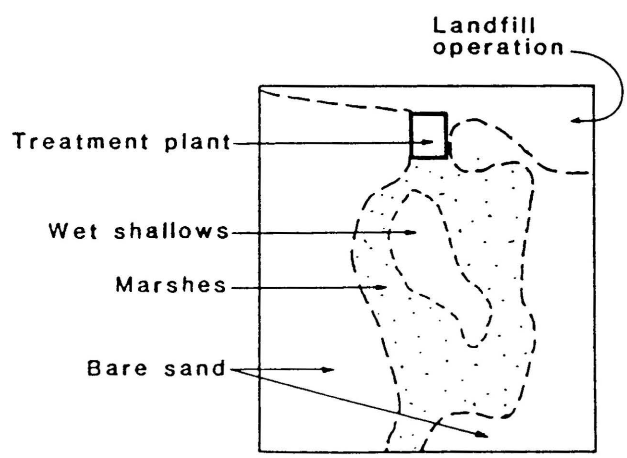
For some years secondarily treated municipal sewage from Port Aransas, Texas, has been released on sandy mud flats along an estuarine channel. The water, rich in nutrients, produced a freshwater marsh around the outfall and a typical salt marsh outside this that is rich in wildlife and a center for bird studies (see figure 5.2). The salt marsh exchanges with the estuaries as the sea level rises and falls so that crabs, fish, and shrimp utilize the marshes as a source of food, especially during their juvenile stages. Recent studies have been made by Pulick (4) of the processing of nutrients by the marsh. As the population of the town has increased, the size of the marsh has increased. Addition of the fresh water also helps maintain fresh water in the dunes from which water may be pumped for irrigation. The self-organizing marsh treatment system at Port Aransas can serve as a model for other communities, both along the coast and inland. Using wetlands to accept secondarily treated wastewater is now widely practiced in Florida, Michigan, and other states (5)(6)(7).

Data about the Port Aransas marsh was collected and the emergy involved in the water and its processing was evaluated in table 5.3, which is based on details in appendix 21. Figure 5.3 is a systems diagram showing how the marsh and wildlife contribute to the economy by performing tertiary treatment

Figure 5.2

View of Southern Part of Port Aransas, Texas, Showing City Sewer Treatment Plant and the Marshes Generated by Effluents

Note: Inset identifies a shallow water area in the center surrounded by a light colored, freshwater cattail marsh that is fringed by a saltwater Spartina marsh.



of sewage effluent, supporting fisheries, and serving tourists. The water and the tidal interactions contribute over $200,000 per year macroeconomic value to the local economy.

MARINE RESOURCES

Distinctive, flat, and fertile, the coastal zone of Texas contains valuable marine resources. Shown in figure 5.4 are the coastal counties, connecting rivers, coastal cities, bays, and estuaries, 500 miles of beaches and the continental shelf. The marine waters support sport and commercial fishing, process and recycle wastes, cool power plants, provide aesthetics and recreation, attract tourists and retirees, facilitate cheap transportation, and supply oil and gas from offshore reservoirs.

An overview of the coastal system and the way the special marine resources support economic interfaces and attract investments is shown with the energy systems diagram in figure 5.5. The sea-level fluctuations, tides, wind and waves, sun, rain and discharging rivers are shown operating the environmental systems of continental shelf, beaches, estuaries, and coastal wilderness. Because the coastal counties have special marine resource inputs, they support special economic activities that are amplified by the external emergy and dollars they attract.

A preliminary emergy analysis was made of 23 coastal counties to evaluate the marine resources and compare these with water and other inputs to the coastal zone (appendix 20). By using emergy evaluation to arrive at macroeconomic values, the full contribution of marine resources to the economy was estimated (table 5.2). These values are larger than those based on costs and market prices. Some of the indirect estimates could be improved with better data. Among items yet to be evaluated are the sediments in the rivers; the impact of hurricanes; the input of tourists; the biological work of the bay in waste treatment, estimable from primary production; and coastal shipping.

Referring to table 5.2, the values for oil and gas production, use, and export in 1983 were an order of magnitude larger than other resources. Emergy analysis shows that rich fuels ultimately contribute a much higher dollar value to an economy than is paid to process them. However, like Texas as a whole, the coastal area sends much of its oil and gas resource value out to stimulate other economies. Even so, its own oil use ($53 billion macroeconomic value) is far in excess of the other resources. It is little wonder that priorities have gone to oil and gas production over environmental concerns. With sharply declining oil and gas production, the coastal economy is now changing and becoming more dependent on the renewable marine resources.

The total environmental renewable marine inputs are about $8 billion macroeconomic value per year. When matched with investments, the macroeconomic contribution is estimated by multiplying by the investment ratio characteristic of Texas and the United States generally, which is 7 to 1. The result, $56 billion per year, is the economy of the coastal zone that may be supported by these resources. These macroeconomic value perspectives show the importance of better management of the marine resources so that destructive uses do not diminish economic contributions. The evaluation is a justification for more effort by government to regulate and facilitate

Figure 5.3

Energy Systems Diagram of the Interface Between the Wetlands, Sewage Plant, and Contributions of the Marsh to the Local Economy of Port Aransas

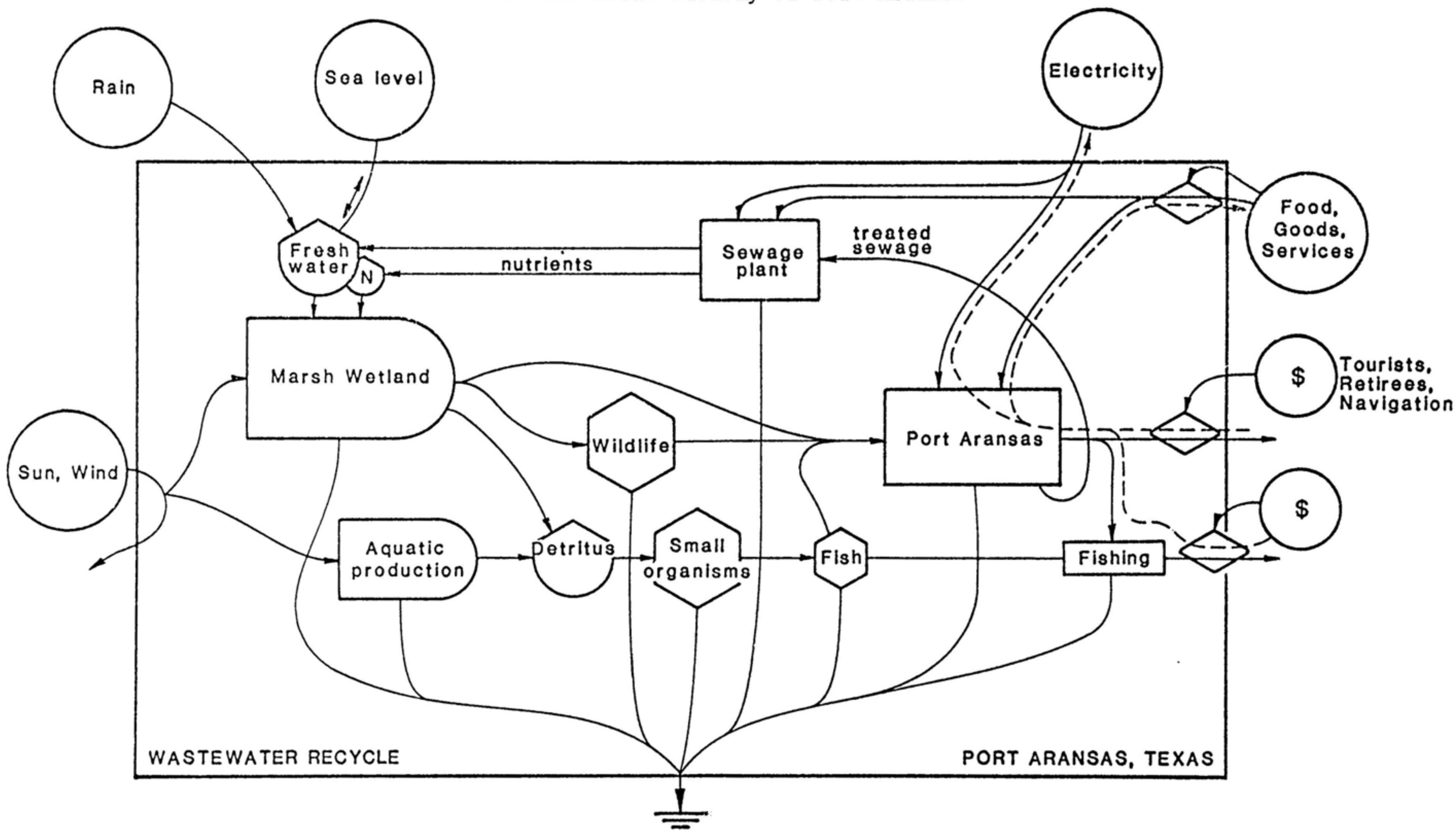
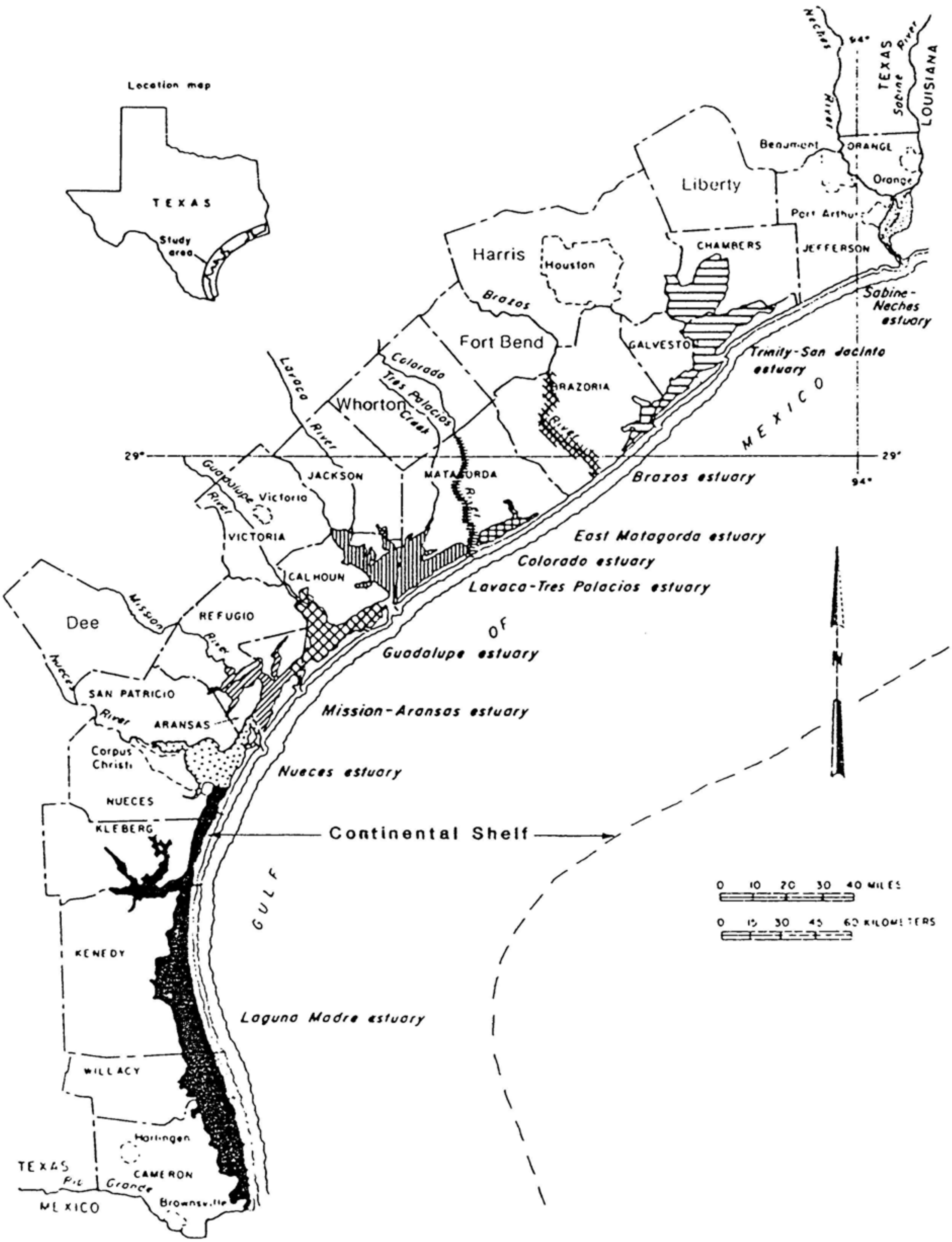


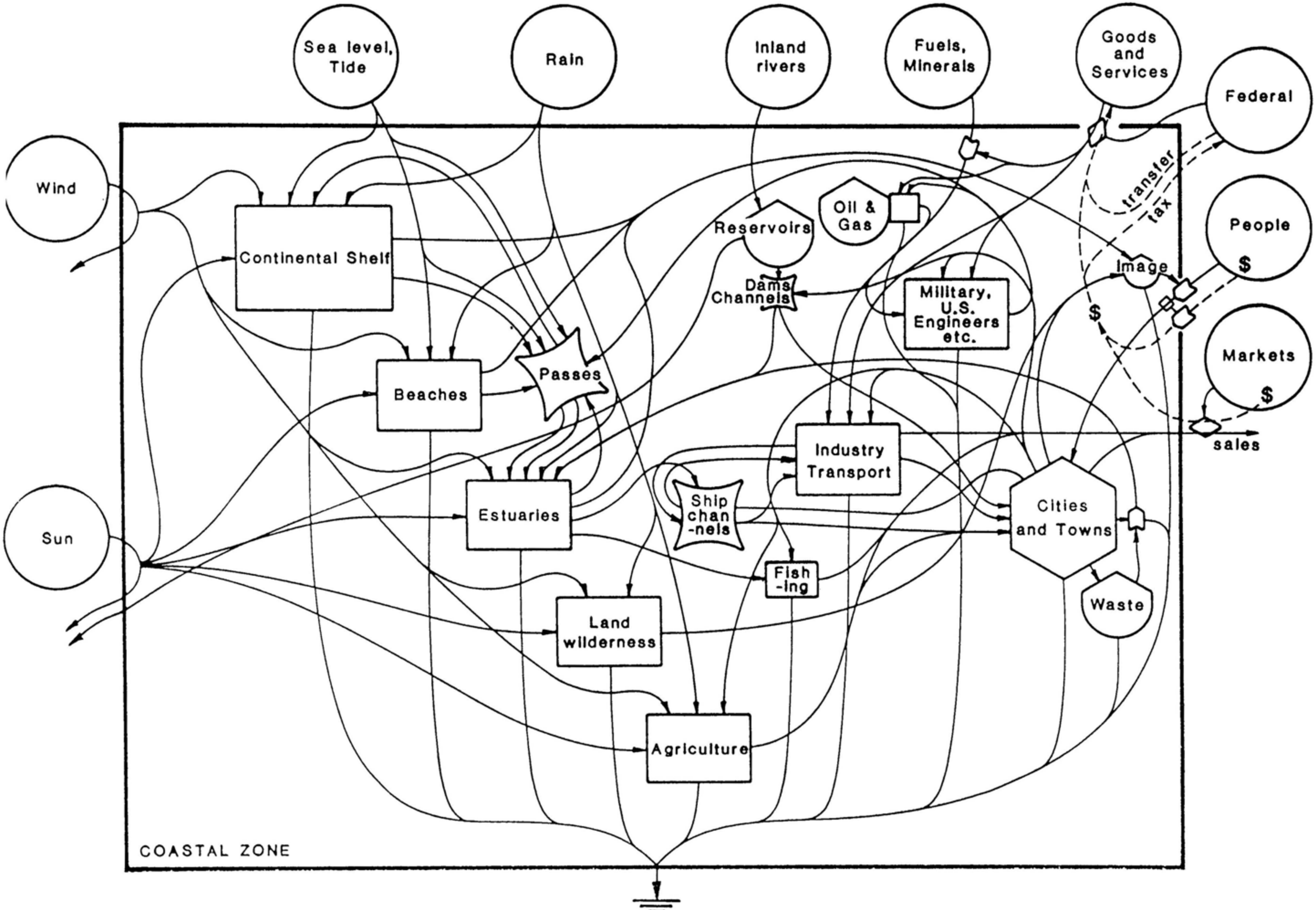
Figure 5.4

Coastal Zone of Texas with Rivers, Bays, Coastal Counties



Source: Modified from Texas Division of Water Resources, 1983.

Energy Systems Diagram of the Coastal Zone of Texas
and the Way the Marine Resources Generate the Regional Economy



Note: For symbols see figure 2.1.

compatible uses that maximize the work of the natural ecosystems. Like agriculture, fisheries have much higher macroeconomic contribution to the economy than is inferred from prices of raw products. Sports fisheries have a larger value than the commercial fishing.

Most of this renewable environmental resource is marine. As fuels become less important, the coastal counties will gain relative greater importance because of the extra emergy base. In other words, they will recapture some of the primary importance they had in earlier times.

Table 5.1 shows that freshwater contributions are a major part of marine resources, \$3.5 billion directly and \$24.5 billion in potential attracted economic investment. Without freshwater inflows, bays become briny, marshes disappear, and part of the biological treatment capacities are lost. To justify diversion of these freshwaters away from the bays, alternative proposals should demonstrate this level of economic potential. High rates of water loss from reservoirs in arid regions reduce macroeconomic value of proposals to divert waters.

ENDNOTES

(1) Bomar, G.W. Texas Weather. University of Texas Press, Austin, 1983, 265 pp.

(2) Mean of 19 stations. Source: Texas Almanac.

(3) Calculation: (1 m3 oil)(0.9 E6 g/m3)(3.7 E4 J/g)(5.3 E4 sej/j) /(2.4 E12 sej/\$)

(4) Pulick, W.M. Vascular Plant Production in Southern Texas and Limitations by Nutrient or Freshwater Inflow Stress. Project proposal, The University of Texas Marine Science Institute, Port Aransas, 1985.

(5) Ewel, K. and H.T. Odum eds. Cypress Swamps. Gainesville: University of Florida Press, 1984.

(6) Middlebrooks, E.J. ed. Water Reuse. Ann Arbor, Mich: Ann Arbor Science Publishers, 1982.

(7) Godfrey, P.J., W.R. Kaynor, S. Peczarski, and J. Benforado eds. Ecological Considerations in Wetlands Treatment of Municipal Wastewaters. New York: Van Nostrand Reinhold Co., 1985.

Chapter 6

THE ROLE OF ENERGY IN THE TEXAS ECONOMY

Historically, Texas led the nation in the development of oil and gas as a means for world industrial and urban development. Then after 70 years of economic growth based on fossil fuels, oil and gas reserves began to dwindle, and the basis for the economy of Texas has had to be reorganized. In this chapter emergy evaluations are used to examine future potential and to recommend public policies for energy for the future.

EMERGY BASIS FOR THE TEXAS ECONOMY

The main resources contributing to the Texas economy were evaluated in emergy terms in figures 4.1 and 4.2. Details are in appendix 9. By expressing the energy in emergy units, different kinds of energy are expressed on a similar basis regarding their ability to generate real wealth. The environmental renewable resources, sun, wind, ocean waves, tides, and rain, contribute through their support of agriculture, forestry, fisheries, natural watershed vegetation, and wildlife. But the indigenous renewable energies are only 3 percent of the total emergy used each year; 66 percent of the total emergy is from using fossil fuels (oil, natural gas, coal, lignite). Another 26 percent of the emergy comes from selling oil and gas to the rest of the nation and other countries and using the money received to buy goods and services from out of state. As rich fuel deposits become scarce, less fuel is available to use and to sell. Domestic oil and gas become less important to the economy each year.

Energy Reserves

Summarized in table 4.2 are the resource reserves in Texas expressed in macroeconomic dollars estimated from emergy units. Comparing the stored reserves with current rates of use provides a rough estimate of the time these can last. At present rates of use only 9 years of supply remain (table 4.2, second column). Increasingly, the fuels will have to come from outside of Texas, and money to pay for them will have to come from the sales of other commodities.

Economic Effect of Fuels and Net Emergy Yield

Fuels contribute much more emergy to an economy than is used to locate, mine, refine, and process the fuels. The ratio of emergy yielded to that used in bringing fuel into use is the net emergy yield ratio. Rich oil deposits near the surface once yielded 50 times more macroeconomic value to the economy than was used (net emergy yield ratio was 50/1). At present typical deposits have a yield ratio between 6/1 and 10/1.

Each year more effort (more emergy) goes into drilling for oil and gas located deeper underground and further offshore. More dry holes that yield nothing result from this effort. Also, drilling conditions, such as the chance of blowouts, are much worse as wells are drilled deeper. In other words, the amount that fuels contribute to the economy beyond that required to operate the oil industry is decreasing.

Economic Stimulus of Using Fuels

Because fuels contribute 6 to 10 times more to economic wealth than is used to get the fuel, using fuel helps an economy much more than selling fuel. Except when prices are artificially raised (see discussion below), fuel prices mainly provide the seller money to reimburse costs. Money pays for the human costs involved in processing fuel, not for the full amount of wealth that is generated in fuels when made by natural processes.

Selling oil and gas provides income to the oil industry. However, using gas and oil increases the productivity of most of the sectors of the economy, increasing dollar circulation many times more than the money used to pay for the fuels.

NET EMERGY BALANCE OF BUYING AND SELLING OIL AND GAS

Over the years Texas has sold oil and gas to the world, contributing much more to buyers' economies than was received for the fuel. Even when gas and oil prices were high, users such as the New England states were stimulated, because the net emergy benefit to them was 6 times larger than the emergy in their payments. The Texas economy only became prosperous when it developed enough high-energy agriculture, industry, and urban workers to use more of the energy in Texas.

As figure 4.2a shows, 57 percent of the oil and gas produced from wells in Texas goes out to enrich other economies that use it. However, half of the oil and gas used within Texas is imported. Although importing oil takes some money out of state, importing oil contributes much more wealth and causes many more dollars to circulate as part of the gross economic product.

The United States benefits from using Mexican oil with 6 to 10 times more emergy received than paid. Mexico would help its economy by using its oil at home, rather than selling it abroad.

The dollar circulation through the oil and gas industry is about 20 percent of the total economy of Texas. When fuel prices rise, as with the Arab embargo of 1972, this sector is stimulated by receiving more money for its product. The price jump was enough to stimulate the oil and gas portion of the economy of Texas and to provide more taxes to run the state government. However, the rest of the economy is diminished by using less fuel, which reduces production because there is less net emergy contribution.

When prices fall, the oil and gas sector receives less money, but the rest of the economy is stimulated by the cheap fuels. With the oil and gas sector now relatively small, the state as a whole tends to benefit by cheap oil. This conclusion is opposite to public opinion which does not generally recognize the large net emergy contribution that results from using more fuel.

In order to determine the net benefit to an economy of a trade or sale, the emergy of the trade can be evaluated as illustrated in figure 2.5. The exchange ratio is the ratio of the items exchanged. Table 6.1 summarizes the emergy contributed or lost from the economy of Texas by buying and selling oil and gas outside. The price of oil and gas has fluctuated widely since 1972 due to OPEC price fixing and other factors. Thus, the emergy paid out or received with buying and selling oil has varied widely. When the price was high, $34 per barrel, the emergy received by Texas for oil was one-fifth of the outgoing emergy.

Table 6.1

Macroeconomic Benefit of Exports and Imports of Fuel from Texas.

Category	Sale value $/yr (billions)	Macroeconomic value
Exports		
Natural gas	6.7	41
Oil	23.1	104
Imports		
Oil	18.	81

Note: Contributions to macroeconomic value determined by emergy evaluations for 1983. For details see appendices 9 and 11.

NET EMERGY OF ALTERNATIVE SOURCES OF ENERGY

What sources of energy can replace the oil and gas that are now the basis for most of the economy of Texas (and the United States as a whole)? Table 6.2 indicates the net emergy yield ratio for various energy sources that have been suggested as alternatives. To be economical, a primary energy source must have a net emergy yield ratio as high as the ratio for purchasing oil on the world market. At present prices the net emergy yield ratio obtained by buying oil is about 10 to 1. Most of the sources in the table are less than this. An example of the net emergy evaluation of a fuel is given for lignite in the next section.

Although solar energy is abundant, it is so dispersed that it requires a great deal of work to concentrate it. Consequently, using technology or collecting biomass made by plants to concentrate solar energy into fuels yields low net emergy yield ratios. Other sources, like tides and ocean waves, are only available locally or in small amounts.

After prices of foreign oil become too high for its use to be economical and after Texas' oil and gas reserves are depleted, the principal source of fuel available to Texas is western coal. There are enough reserves to last many years, and the net emergy yield ratio, even after transport to Texas, competes with present oil and gas.

One of the fuels still available in Texas is lignite, a form of coal with more moisture content than other types of coal. Since the 1973 Arab embargo, several power plants using lignite have been built in Texas. By analyzing one of these, the Big Brown Mines and Power Plant at Fairfield, Texas, this source of energy may be compared with oil and gas and other alternatives.

A diagram of the plant system is given in figure 6.1. On the left is the mining operation, which uses electric-powered draglines to remove the overburden of soils. Then smaller equipment loads the lignite into ore carriers that travel several miles to the power plant, which is shown on the right side of the diagram. After some processing, the fuel is burned to generate the steam to turn generators and produce electricity. Cooling is provided by water that circulates through the plant, into a lake, and back again. Water that evaporates is replaced from groundwater. After mining, the for pasture, reseeded, and irrigated to reestablish a

Table 6.2

Benefit of Using Alternative Energy Sources.

Source		Net emergy yield ratio
Texas lignite [1]		6.8
Coal [2]	1983 prices	11.8
	1986 prices	11.4
Natural gas [3]	1983 prices	5.6
	1986 prices	7.8
Oil [4]	1983 prices	4.1
	1986 prices	7.9
Hydroelectricity [5]		2.8
Plantation wood biomass [6]		2.1
Solar water heater [7]		0.18
Texas windmill energy [8]		0.03

Note: Ratio of emergy contributed to generate gross economic product to emergy required from the economy for processing.

1. Texas Lignite, 6.8. See appendix 23.

2. Coal used in Texas power plants

Costs of coal at electric utility power plants: price per ton multiplied by short tons of coal consumed: source: Department of Energy: DOE/EIA Annual Energy Review (1984), p. 163 and k. McClevely, DOE/EIA. Washington, Telephone Interview by Scott Hancock, May 8, 1986.

1983:

Yield:(15.6 E15 btu/yr)(1054 j/Btu)(3.98 E4 sej/j) = 6.54 E23 sej/yr

Feedback estimated from cost: ($22.1 E9)(2.6E12 sej/$) = 5.74 E22 sej/yr

Ratio: (6.54 E23 sej/yr)/(5.74 E22 sej/yr) = 11.4

1986:

Yield: (18.2 E15 btu/yr)(1054 j/Btu)(3.98 E4 sej/j) = 7.63 E23 sej/yr

Feedback estimated from cost: ($23.4 E9/yr)(2.2 E12 sej/$) 5.14 E22 sej/yr

Ratio: (7.63 E23 sej/yr)/(5.14 E22 sej/yr) = 11.8

3. Natural gas used in Texas power plants:
Department of Energy: DOE/EIA.; Monthly Energy Review (December 1985), P. 81. and K. McClevely, DOE/EIA. Washington Telephone Interview by Scott Hancock, May 8, 1986.
1983:
Yield: (3.00 E15 Btu/yr)(1054 j/Btu)(4.8 E4 sej/j) = 1.52 E23 sej/yr
Feedback estimated from cost: ($10.4 E9/yr)(2.6 E12 sej/$) = 2.70 E22 sej/yr
Ratio: (1.52 E23 sej/yr)/(2.70 E22 sej/yr) = 5.6
1986:
Yield (3.19 E15 Btu/yr)(1054 J/Btu)(4.8 E4sej/j) = 1.61 E23 sej/yr
Feedback estimated from cost: ($9.4 E9/yr)(2.2 E12 sej/$) = 2.07 E22 sej/yr
Ratio: (1.61 E23 sej/yr)/(2.07 E22 sej/yr) = 7.8

4. Oil used in Texas power plants:
Heavy oil consumption by electric utilities multiplied by 5.6 E6 Btu/barrel.
Department of energy: DOE/EIA. Electric power Annual(1984), P. 46 and K. McClevely, DOE/EIA Washington. Telephone Interview by Scott Hancock, May 8,
1983:
Yield: (1.37 E15 Btu/yr)(1054 J/Btu)(5.3 E4 sej/j) = 7.65 E22 sej/yr
Feedback estimated from cost: ($7.1 E9/yr)(2.6 E12 sej/$) = 1.85 E22 sej/yr
Ratio: (7.65 E22 sej/yr)/(1.85 E22 sej/yr) = 4.1
1986:
Yield: (1.12 E15 Btu/yr)(1054 J/Btu)(5.3 E4 sej/j) = 6.26 E22 sej/yr
Feedback estimated from cost: ($3.6E9/yr)(2.2 E12 sej/$) = 7.92 E21 sej/yr
Ratio: (6.26 E22 sej/yr)/(7.92 E21 sej/yr) = 7.9

5. Hydroelectricity, 2.8
Analysis of Tucurui Dam in Brazil by Brown, M.T. Energy Analysis of hydroelectric dam near Tucurui. pp. 82-91 in Energy Systems Overview of the Amazon Basin. ed. by H.T. Odum, M.T. Brown and R.A. Christianson. Center for Wetlands, University of Florida, Gainesville, 1986.

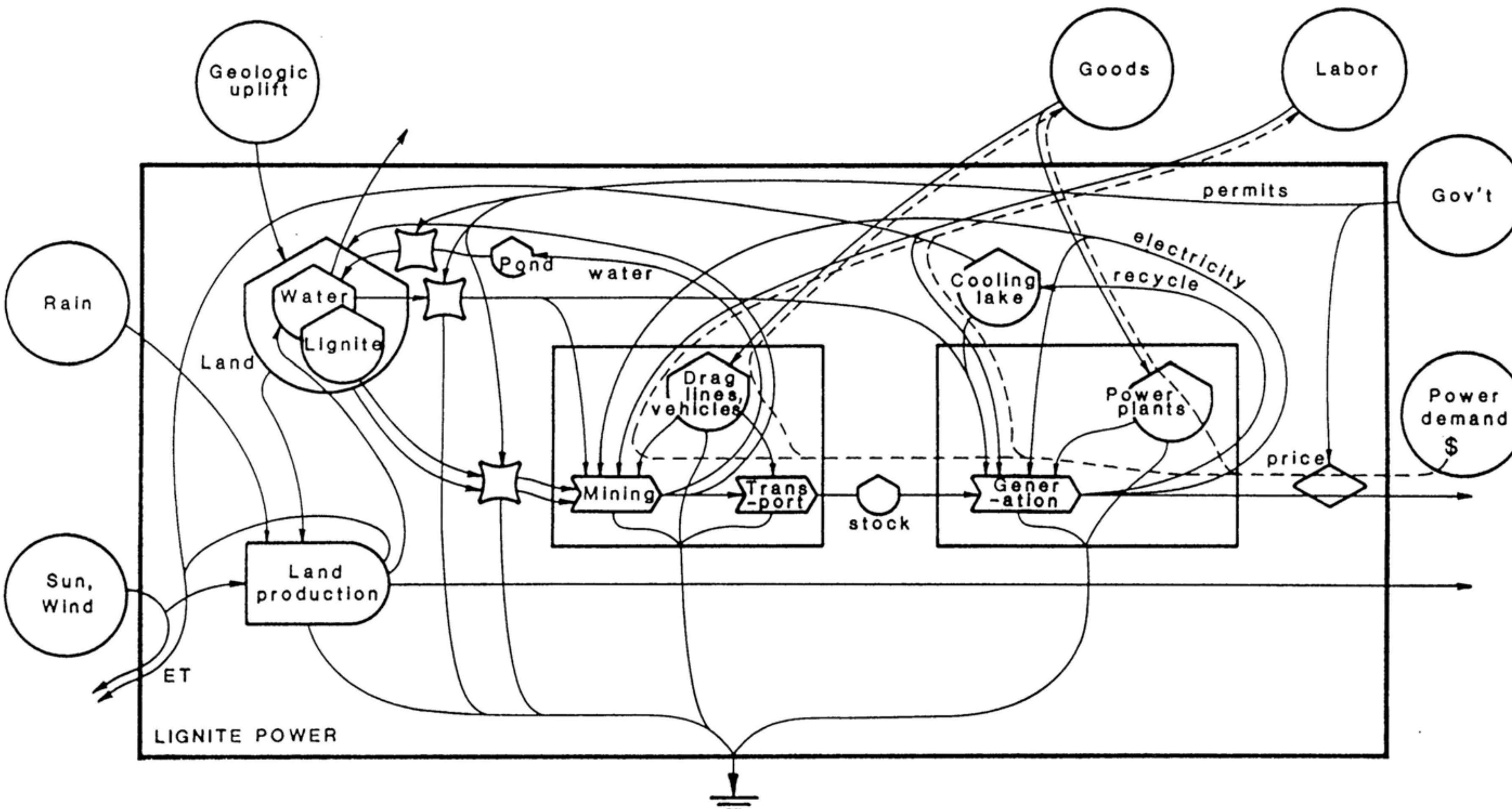
6. Plantation wood biomass, 2.1
Pinus radiata in New Zealand from Odum, H.T. and E.C. Odum eds., Energy Analysis Overview of Nations. Working Paper, WP-83-82, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1983.

7. Mechanical energy of heat gradient from solar water heater, 0.18
From Zucchetto, J. and S. Brown, "Comparison of the fossil fuel energy requirements for solar, natural gas, and electrical water heating systems." Resource Recovery and Conservation 2:283-300, 1977.

8. Mechanical energy delivered by a Texas farm windmill, 0.03.
See table 5.1.

Figure 6.1

Mining and Conversion of Lignite to Electric Power at the Big Brown Plant at Fairfield, Texas

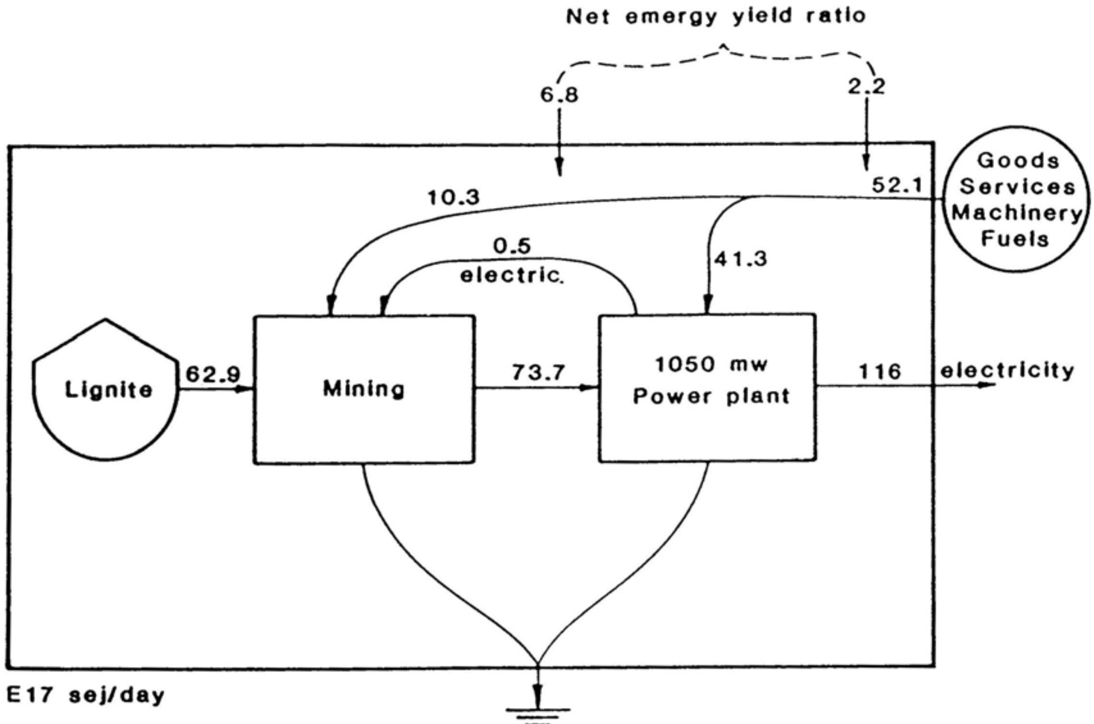


Note: See evaluations in appendix 23.

All the inputs and outputs were evaluated in emergy flow units. Details are given in appendix 13. Figure 6.2 is a summary relating the emergy flow of input and yield. The net emergy yield ratio (table 6.2) is 6.8, a yield as high as many alternative sources of fossil fuels now available. It yields as much emergy to the economy as buying oil at a price of $26 per barrel (1986 dollars). Lignite that is accessible to mining, such as that at Fairfield, can support a modern economy. However, as table 4.2 indicates, the lignite reserves in Texas will last only about 14 years at the present rate of use.

Figure 6.2

Summary of Emergy Flows at the Lignite Plant Diagrammed in Detail in Figure 6.1



Note: Net emergy yield ratio is calculated after mining and after production of electric power.

After the lignite is converted into electricity, the net emergy yield ratio is 2.2/1, which compares reasonably well with other electric power plants. The efficiency is not quite as high as plants that use a more concentrated fuel with less water content.

The environmental disruptions and efforts at environmental protection and reclamation associated with the mining and generation of electricity were evaluated in emergy units as part of the calculations (appendix 23). These were found to be small compared to those of the lignite and electricity yielded. In other words, since the contribution of emergy to the total economy is much greater than the environmental costs and losses, the operation is macroeconomically justified. The reclamation is justified because the increase in emergy of land productivity is larger than the emergy used.

ENERGY CONSERVATION

The efficiency of many aspects of energy use in Texas can be increased. Many industries use only part of the heat that is generated by fuel processing. By passing on this excess energy to another user, more of the resource goes into useful products. Some industries can generate electricity with their excess steam and sell it to public utilities. Combining energy users in order to conserve energy and decrease costs is called <u>cogeneration</u>.

Many aspects of energy use in Texas are luxury uses. Eliminating such luxuries as unnecessarily large cars and trucks, superfluous roads, and excessive use of air-conditioning will save energy for uses that contribute more to the economy. Energy conservation stimulates an economy by using resources for productive purposes. Smaller cars cost less so that less money is required for otherwise similar living standards. Wages can be less. Reduced costs make products competitive on world markets and provide more jobs.

EMERGY ANALYSIS OF TEXAS HIGHWAYS

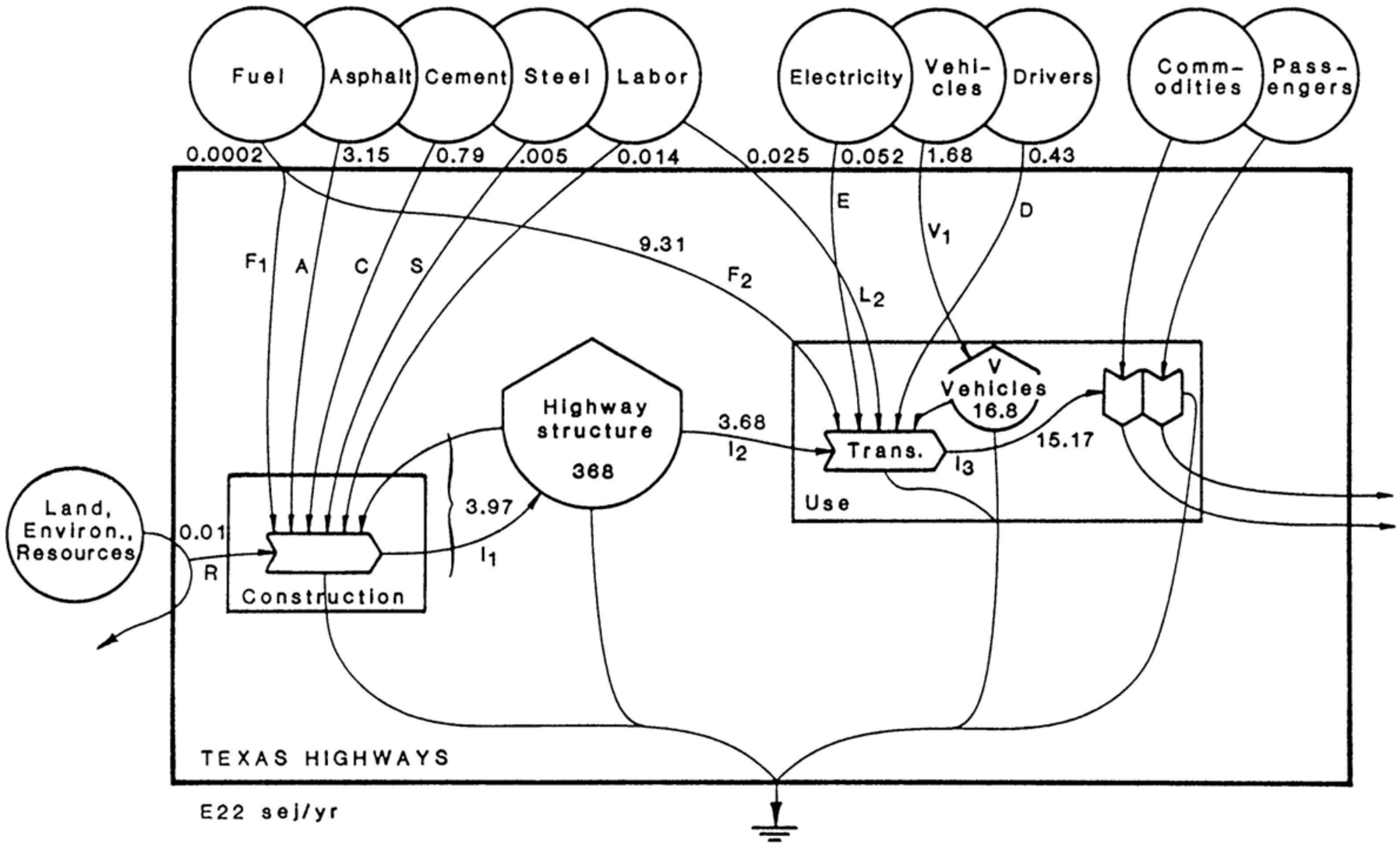
Figure 6.3 is an emergy analysis of Texas highways and their energy requirements. The inputs to construction and maintenance of Texas highways are summarized on the left, and inputs to use of the highways are summarized on the right. Numbers on the pathways are flows of emergy per year. Details are given in appendix 24. Note the very large inputs to construction in asphalt and cement, and inputs of vehicles and drivers to highway use.

Notice also the very large amount of emergy stored in the highway structure. The macroeconomic value (obtained from the emergy evaluation) of the existing highways is $1.4 trillion (table 6.3). This is a much larger figure than the money spent on the roads. Money is spent only for the human services involved directly and indirectly, whereas the macroeconomic value includes the unpaid contribution of nature in generating the resources in the asphalt and the cement.

The historical record of highway construction and maintenance was examined and construction in 1986 was found to be mainly replacing deterioration without many net gains or losses in road structure. If depreciation is roughly in balance with construction and replacement, the

Figure 6.3

Emergy Basis for the Construction and Use of Texas Highways Based on Calculations in Appendix 24



Source: Lyu, Wernhuar. "Emergy Analysis of Highway Transportation in Texas." Unpublished student report for Policy Research Project course, LBJ School of Public Affairs, The University of Texas at Austin. 1986. pp. 130-157.

Table 6.3

Macroeconomic Values of Texas Highways

Category	Macroeconomic value* Billion $
Stored emergy	
in highways	1415.
in motor vehicles	64.4
Maintenance per year	
Steel, cement, asphalt	15.
Services	0.05
Annual highway use	
Fuels used	35.8
Use depreciation	14.1
Vehicle replacement	6.4
Drivers service	1.7

Source: Lyu, Wernhuar. "Emergy Analysis of Highway Transportation in Texas." Unpublished student report for Policy Research Project course, LBJ School of Public Affairs, The University of Texas at Austin. 1986. pp. 130-157.

Note: See appendix 24.

percentage of depreciation can be evaluated. The emergy per year is 1.1 percent of the stored emergy in highways, making the depreciation rate about 1 percent per year.

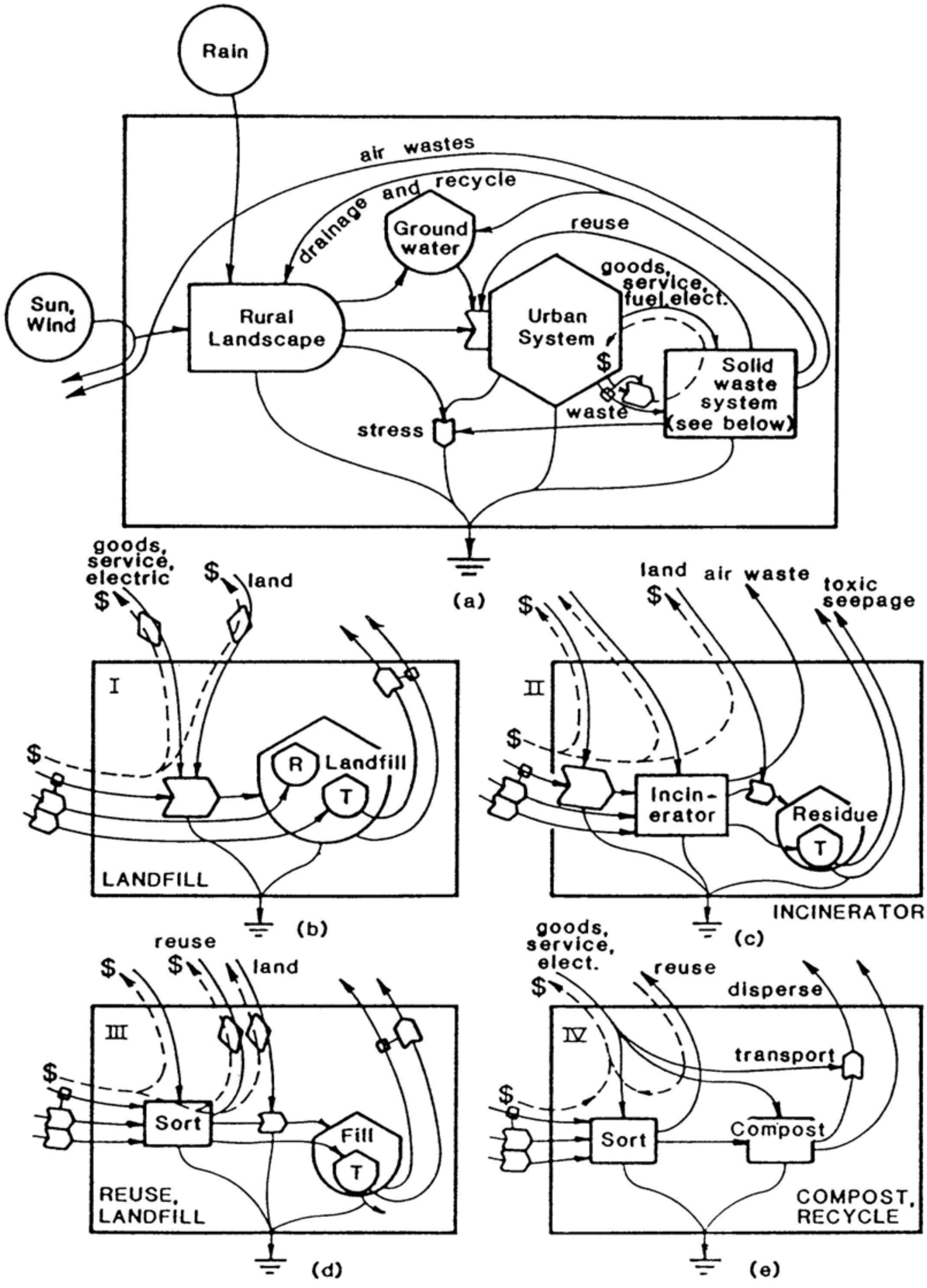
Because fuels and raw materials are used that have high net emergy yield ratios, constructing highways and operating vehicles is a net emergy contribution to the economy. This is why economic growth in the past was facilitated by highway construction. As net emergy yield ratios of fuels decline, highway construction will contribute less to the economy.

With further decline in available energy in Texas and rising costs for obtaining energy and energy-rich materials like asphalt and cement, further growth of highway assets may not occur. Eventually reductions in highways will be required when resources available for use decrease. When inputs decrease, decisions can be made as to which roads are less essential so that reductions in highways to be maintained can be made.

Highways are one of the main structures of the economy. Emergy evaluation shows they are worth many times more than the values assigned by economic evaluations of cost. The emergy analysis of other infrastructures of the urban economy, such as buildings and utilities, may be similar. The high emergy in infrastructure may not be maintainable at its present high level with energy availabilities anticipated in the future. Because there is a relatively slow depreciation, it will be some years before the inability to maintain present structures reaches public consciousness. Reducing excess infrastructure is part of energy conservation.

Figure 6.4

Alternative Systems of Solid Waste Disposal



Note: R refers to recyclables; T refers to toxic waste. (a) Relation of solid waste system to an economic landscape; (b) landfull system; (c) incinerator system; (d) reuse and landfill system; (e) reuse, compost and recycle.

SOLID WASTES AND LANDFILLS

At present the solid wastes of urban society are buried in landfills. Each year more and more land is taken out of productive use. The wastes, often carrying toxic substances, are leaching into groundwaters. Each year the hazard to the economy increases. In an emergy analysis of the municipal solid waste disposal in Texas, Van der Loop found that the total macroeconomic value estimated from the emergy of the solid waste components was $25.7 billion per year, nearly 10 percent of the gross state product of Texas (1). The present system of waste disposal is increasingly a drain on the economy. If all these potential resources could be either reused in the economy or distributed to the environmental systems in a way that would stimulate production of soil and vegetation, it would result in savings in energy, reduced taxes, and an increased ability of the economy to compete in world markets. By-products should never be regarded as wastes, but as resources for use by the environmental life support system or by the human economy.

Five systems of disposal were considered, including (I) landfill; (II) reuse of some parts of present solid waste with the rest into landfill; (III) incineration with landfill of the remains; (IV) reuse of some parts, incineration and landfill of the rest; and (V) reuse of some parts, with compost and dispersal of the remainder to range and forest lands. Figure 6.4 provides diagrams of the various systems of disposal. Table 6.4 summarizes the results. Details are given in appendices 25-29. The last one (reuse, compost, and dispersal) contributes the most net benefit to society.

Table 6.4

Macroeconomic Value of Alternative Systems of Solid Waste Disposal.

	Method	$ (billions)
I	Landfill	- 25.7
II	Reuse and landfill	- 9.2
III	Incineration and landfill	- 10.1
IV	Reuse, incineration, and landfill	+ 3.2
V	Reuse, compost, and disperse	+ 9.2

Source: Adapted from Van der Loop, B. 1986. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, The University of Texas, LBJ School of Public Affairs, THE TEXAS SYSTEM, pp. 235-255.

Note: Contribution to the economy indicated by + or -. For details of calculations, see appendices 25-29.

PUBLIC POLICY ON ENERGY

Economic value is often defined as the money individuals will pay for something. But macroeconomic value used in this study, as determined from emergy, is the value to the public economy (chapter 2). It is the gross economic product directly and indirectly produced by items of value. Plans and policies are recommended to maximize macroeconomic value.

The two different means for evaluating the contribution of fuel cause very different public policy recommendations. Table 6.5 compares the effect on the Texas economy of public policy alternatives according to two concepts, one that uses the price of fuel as the measure of its role in the entire economy and the other that uses the emergy contribution as a measure of the role of fuel in the entire economy.

Conservation

Conservation measures which that utilization more efficient without decreasing the total emergy used ultimately generate more wealth per unit of resource used. This energy efficiency approach is sometimes called energy conservation. Examples have already been given of increasing the efficiency of transportation by using smaller vehicles and fewer roads. Utilizing wind in water-pump farm windmills (table 5.1) saves electrical energy for additional economic contribution.

The disposal of municipal solid waste (figures 5.2 and 5.3) in a form usable by ecological systems requires a minimum of technological treatment and better utilizes energy resources. Nature's production and consumption processes are utilized with large savings in time and materials.

Fuel taxes

Because taxes reduce energy use, they reduce the gross economic product 6 to 10 times the dollar value of the tax. Taxes should never be placed on fuels or electricity for this reason. Fuels and electricity should be exempted from all taxes.

For many years money reinvested in oil drilling was exempt from income tax. This policy was successful because of the amplifier effect of fuel contributing more than its cost. Excess profits tax on oil should be replaced by legislation that ensures that excess profits are reinvested in energy development, which has a competitive net emergy yield.

Oil Import Tax

Political leaders in Texas have sought an import tax on foreign oil to encourage more use of oil and gas produced in Texas and less use of oil from abroad, where costs are lower. Such a tax would increase the dollars in the oil-gas sector of the economy; however the effect on the rest of the economy would be to dampen productivity. The net effect in Texas would be negative because most of the economy is no longer in the oil-gas sector.

PRIORITIES AND DIFFERENTIAL CHARGES FOR FUELS AND ELECTRICITY

When energy supplies are scarce, priority should be given to agriculture and industry, a policy that was successful in World War II. The reverse policy was implemented in the 1973 shortages, resulting in industries and jobs being idle because households were given priority.

Charges for energy should not be greater for the production sectors of the economy than for the consumers. Because of the amplifier effect, charging agriculture and industry more inhibits the economy, causing loss of jobs, while encouraging unessential waste by the well-to-do consumers. In Austin, Texas, in 1985, higher electric utility charges were required from industry than from household consumers. This was backwards, because much of the consumers' use of electricity was not essential and did not contribute to production. Keeping high technology industries within Texas and the United States is already threatened by foreign competition. Keeping energy as cheap as possible for them gives their products a several-fold boost.

Changes in World Price

A decrease in world fuel prices depressed the oil and gas sector of the Texas economy because the Texas oil and gas that is still available is so deep underground and far offshore that the cost of production is higher than in many other countries. Not only was less money received per barrel of oil, but in many wells it did not pay to keep pumping. Investment dollars went elsewhere also, since chances of finding cheap oil in Texas are much less than in newer fields elsewhere. Because state government was running on oil and gas taxes, cutbacks in government services were anticipated. The public interpreted all this to mean that the decrease in fuel price would hurt the whole Texas economy.

However, the emergy evaluation method suggests that the long-range effect of lowered prices will be a stimulated economy because other sectors will have greater increases than the losses in the oil-gas sector (see typical calculations in table 6.5). The increased sales tax on the stimulated part of the economy is likely to exceed the tax losses from the oil and gas sector after a period of transition in which those released from oil and gas jobs are reemployed by growth in the other sectors.

Eventually, as the net emergy yield ratio declines over the whole world (as all the near-surface deposits are used up), production of the remaining Texas deposits will once again be economical (production costs will be comparable). Texas and the United States will be in a much better economic and strategic position by having these fuels then than by using them now.

Public policy to augment economic vitality in Texas should be to make fuels and electricity available to all endeavors at the cheapest possible price, without taxes or embargos, but with measures to ensure efficient use. Policies should encourage as much energy use in Texas as possible and as little sales of fuel out of state as possible.

Table 6.5

Predictions and Policies that Result from Traditional versus Macroeconomic Evaluation of Fuels

Item	Traditional analysis	EMERGY analysis
Change in gross economic product from loss of outside oil sales[1]	- 8.3 E9 $	+ 19 E9 $
Economic amplifier, gross product per oil industry $[2]	3.5	9.0
Using out of state oil in place of in state production[3]	- 8.3 E9 $	+ 122 E9 $
Change in gross economic product if saved money due to low prices is spent on using more fuels[4]	no change	up to 187 E9 $
Effect of oil import tax[5]	positive	negative
Repeal windfall profits tax[6]	positive	positive
Resume Mexican gas import[7]	negative	positive
Raise state taxes on items other than oil[8]	negative	positive

Source: Hancock, S. "The Effect of Changing Oil Price on Texas." Unpublished student report for Policy Research Project course, LBJ School of Public Affairs, The University of Texas at Austin. 1986. pp. 256-275.

1. Change in gross economic product from loss of outside oil sales
   --Traditional analysis: At 1985 levels of production (830.5 million barrels) a $10 drop in the barrel price of oil yields a loss of $8.2 billion dollars (out of a gross state product of $289 billion).
   --Emergy analysis: oil produced at home that is not sold can be used within the home economy later with a contribution to macroeconomic value calculated from net emergy of local oil.

2. Estimated economic amplifier
   --traditional analysis: Bernard L. Weinstein and Harold T. Gross estimate that a one dollar decrease in the yearly average price of oil costs Texas $3 billion in gross state product. $3 billion dollars divided by the product of a $1 per barrel price change times Texas oil output, 1985 (830.5 million barrels) yields an amplifier of 3.5. See "After the Fall," Austin American-Statesman, February 9, 1986, p. j-1.
   --Emergy analysis amplifier of 9.0 based on the net emergy yield ratio with $15/bbl.

3. Using out-of-state oil in place of in-state production
--traditional analysis: See calculation in first item above.
--Emergy analysis: Because of the net emergy of oil, the imported oil has much greater contribution than cost.

4. If half price allows twice as much oil to be purchased, the emergy-evaluated dollar contribution is $127 billion minus the $5 billion spent overseas.

5. Effect of oil import tax:
--Traditional analysis: A $9 per barrel tax multiplied by the estimated 1986 Texas oil production of 815 million barrels boosts the state economy by $8.3 billion. However, it delays diversification of the economy.
--Emergy analysis: negative because raised price of oil diminishes oil used and thus the net emergy contribution to macroeconomic value.

6. Repealing Windfall profits Tax:
--traditional analysis: positive because taxes saved stimulate exploration and production
--Emergy analysis: positive because macroeconomic contribution of a commodity with high net emergy yield ratio is greater than the tax.

7. Resume Mexican Gas Import:
--traditional analysis: negataive, creates downward pressure on price of Texas gas and oil.
--Emergy analysis: positive because there is a large net emergy yield to Texas macroeconomic value of gas at current prices

8. Raise State Taxes on items other than oil:
--traditional analysis: negative, hurts business climate and reduces disposable personal income

--Emergy analysis: positive, upgrades educational system, a better educated workforce can make better use of free (low priced) natural resource inputs, in long run, will attract investments; converts consumer luxury spending to production sectors; some taxes deductable from federal tax.

ENDNOTES

(1) Van der Loop, B. 2986. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, The University of Texas at Austin. LBJ School of Public Affairs, 1986, pp. 235-255.

Chapter 7

THE ROLE OF AGRICULTURE IN THE TEXAS ECONOMY

The agricultural sector is one of the main interfaces between the free renewable resources of sun, land, water, and wind and the urban economy driven by fuel use. The role of agriculture in the Texas economy was included in the overview diagram of Texas in figure 4.1.

Figure 7.1 shows the main inputs to agricultural production, and their relationships: 1. sun, which is abundant in Texas; 2. water, which is sometimes scarcer and generally undervalued (see chapter 5); 3. energy, which also contributes much more to the macroeconomic value of agriculture than the money paid for it (chapter 6); 4. land, increasingly in the hands of fewer owners; 5. erodable soils, which have emergy storages from thousands of years of geological work; 6. giant machines, which may be too costly; and 7. labor, troubled with changing policies on wages, immigration, and foreign competition. Notice that some of the inputs must be paid for while others are freely available. Productivity is high when no ingredient is limiting, and the contribution to the macroeconomic value of the economy is greatest when prices for these ingredients are small.

The primary agricultural systems include beef cattle (range, improved pasture, and feed lots), cotton, grains (winter wheat, sorghum, oats, rice), vegetables, and a diversity of others. Table 7.1 summarizes the economic and macroeconomic values of each of these as determined from emergy analysis.

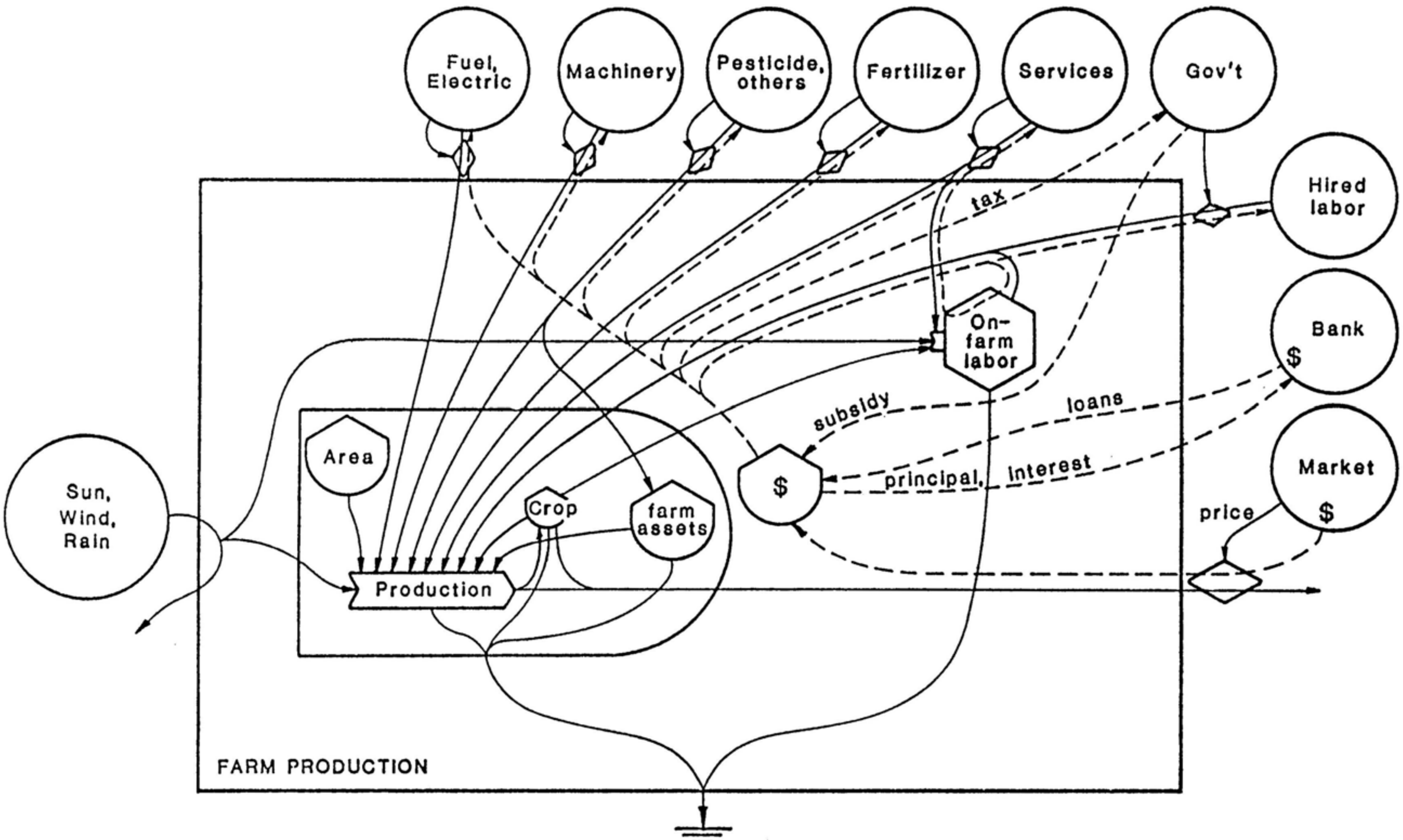
The direct, macroeconomic contribution of agriculture to the Texas economy is 3 times the money paid for the agricultural products (table 7.1). Since agricultural sales are about $9 billion per year, the direct macroeconomic share of the gross economic product due to agriculture is an estimated $28 billion annually or about 12 percent of the gross economic product of Texas. If these preliminary estimates are correct, agriculture contributes much more than is usually attributed to it.

In agriculture, the free inputs of sun, wind, soil, and rain are joined with other inputs that must be purchased (figure 7.2). The more intensive the agriculture is, the more purchased inputs there are. The degree of matching of free emergy with purchased inputs is indicated by the emergy investment ratios in table 7.2. Values for Texas agriculture vary widely. Ratios are small for areas where animals roam without much care but are large for areas of intensive cultivation, such as where cotton is grown.

The investment ratios for Texas agriculture as a whole are small compared to the investment ratio for all economic activity in Texas (7/1). If agriculture were operated at the same intensity as other economic activity, Texas agriculture would be even more important to the gross economy. The potential is given in the third column of table 7.1. Agricultural products, as they pass through the economy, attract matching resources that together generate one-third of the economy. Many people who live in the cities are really part of the farm-based economic system but don´t realize it.

Figure 7.1

Main Ingredients of Agricultural Production



Note: Table 7.1 contains an evaluation of inputs for larger Texas farms. Dashed lines are flows of money.

Table 7.1

Emergy Flows for Larger Farms in Texas

Component	Economic value \$ receipt Billion \$	Macroeconomic value Billion \$	Potential contribution to GNP \$ Billion \$
Cattle and calves[1]	4.19	19.8	69.3
Grains[2]	1.30	4.9	11.4
Vegtetables, fruits[3]	1.27	0.43	.1
Cotton[4]	0.89	5.4	3.6
All agriculture[5]	8.97	27.7	82.
Gross State Product[6]	238.	238.	238.

Source: Snoddy, J. "Farm Size and Agricultural Change." Unpublished student report for Policy Research Project course, LBJ School of Public Affairs, The University of Texas at Austin. 1986. pp. 235-255.

Note: Based on statistics for 13,769 farms with average size 4,284 acres. Details are given in appendix 35.

Column #1 was from Texas agricultural cash receipts, prices received and paid by farmers for 1983, Texas Department of Agriculture, 40 pp.

Column #2 was evaluated by calculating emergy and dividing by the average emergy/\$ ratio for U.S. in 1983 (2.4 E12 solar emjoules per dollar). See appendix 36.

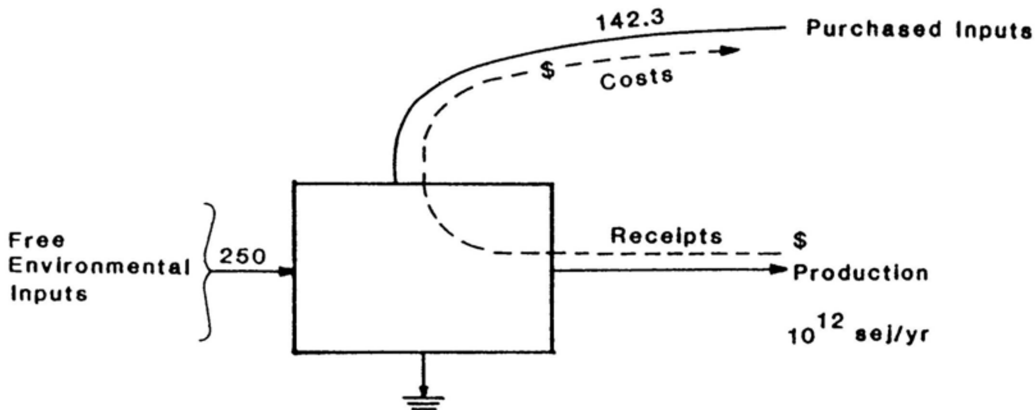
Column #3 is the potential for attracting investments that bring in resources from the main economy estimated as 7 times the macroeconomic value of the water used (2 feet/yr) on areas as follows: cattle-calves, 1.38 E8 acres; grain, 2.27 E7 acres; vegetables, 2.0 E5 acres.

1-5. Details in appendices 36 and 37. Item number 5 is an evaluation of Texas agriculture using aggregated categories. See appendix 39.

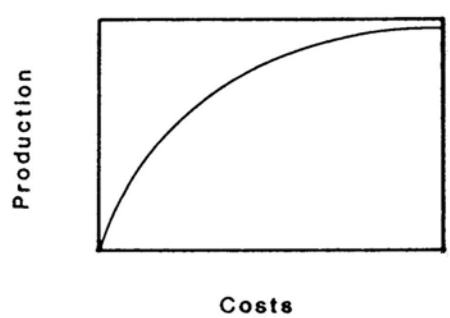
6. Gross State Product: Bureau of Business Research, University of Texas, Austin.

Figure 7.2

Diagram Illustrating the Way Agricultural Production is an Interaction of Free Environmental Inputs and Purchased Inputs



(a)



(b)

Source: Snoddy, J. "Farm Size and Agricultural Change." Unpublished student report for Policy Research Project course, LBJ School of Public Affairs, The University of Texas at Austin. 1986. pp. 235-255.

Note: (a) Diagram with emergy of inputs evaluated for large farms in table 7.1; (b) production as a function of increasing purchased inputs, where free environmental inputs are limited.

Table 7.2

Values of Main Components of Texas Agriculture in 1983

Item		Net Emergy yield ratio	Emergy investment ratio
Texas agriculture	overall[1]	1.75	1.36
	large scale[2]	1.15	5.7
	medium scale[3]	1.51	2.0
Texas cotton[4]		1.10	9.6
Illinois corn[5]		1.08	12.5

Note: For details see appendix 36. Net emergy yield ratio is the ratio of purchased emergy inputs to emergy of water used (the main free environmental input).

Emergy investment ratio is the ratio of emergy yielded to the emergy obtained from the economy.

1. From appendix 39: 27.7/16 and 16/11.7.

2. Farms with more than $100,000 receipts (Snoddy, 1986). From appendix 35 and figure 7.2: E20 sej/yr 1633/1423 and 1423/250.

3. Farms with receipts between $20,000 and $100,000 (Snoddy, 1986). E20 sej/yr: 742/250 and 492/250.

4. See appendix 38: E120 sej/yr 143.2/130 130/13.5.

5. Odum, H.T. "Energy Analysis of the Environmental Role in Agriculture." G. Stanhill, ed. Energy and Agriculture. Berlin: Springer-Verlag, 1984, 192 pp.

VALUE OF AGRICULTURAL PRODUCTS TO THE GROSS ECONOMIC PRODUCT

As illustrated in table 7.2, agricultural products cause many more dollars to circulate in the user economy than is paid for them at market price because the money paid is only for the human services part of agricultural products and not for the large emergy inputs from the environmental system and from other sources within the economy. In other words, an economy buying agricultural products at usual world prices and using those products gains more macroeconomic value, more real wealth, and more contribution to the gross state product than the seller, who receives money that has a much lower emergy buying power.

Macroeconomic Losses from Sales of Agricultural Products

Many agricultural products are sold and used outside of Texas. Traditional views advocate outside sales of agricultural products as favoring the economy. However, emergy evaluations show that processing and using agricultural products generates more economy than selling the products. Table 7.3 shows the net emergy benefits that go out of state due to agricultural exchanges. The macroeconomic advantage to outside buyers is 2 to 17 times more than their payments (table 7.4).

For the benefit of the whole economy, policies should be directed at using raw agricultural products within the state and the country, not maximizing exports of raw products, which simply boost other economies. When raw products can be processed into high-value products, their sale abroad will yield income equivalent to the emergy of the products.

Table 7.3

Emergy Evaluation of Agricultural Exports and Imports from Texas

Item	Sales E9 $/yr	Macroeconomic value E9 $/yr	Difference E9 $/yr
Grain exports	+ 2.7	- 8.9	- 6.2
Imported Mexican vegetables	- 0.29	+ 3.6	+ 3.3
Imported Mexican fuels	- 17.6	+ 33.8	+ 16.2

Note: For details, see appendix 37.

Table 7.4

Emergy Advantages to Buyers of Agricultural Products

Item	Unit	1983 Price Dollars	Emergy Ratio
Water[1]	Acre-foot	50	1.9
Fuel[2]	Gallon	1.00	3.3
Fertilizer[3]	Ton	164	11.8
Beef[4]	100 pounds	55	6.5
Cotton[5]	Pound	0.59	3.9
Wheat[6]	Bushel	3.55	3.5
Wool[7]	Pound	0.83	16.7
Potatoes[8]	100 pounds	8.50	2.0

Note: Ratio of emergy in commodity to emergy of money paid. Prices were given in Texas Livestock, Dairy and Poultry Statistics for 1983, Texas Department of Agriculture, cited in appendix 36.

1. acre-foot water:
(4.05 E3 M^2/Acre)(.3 m/foot)(1 E6 g/m^3)(5 J/g)(4.1 E4 sej/J) = 2.49 E14 sej
Emergy ratio: (2.49 E14 sej)/($50*2.6 E12 sej/$) = 1.9

2. one gallon fuel:
Emergy ratio: (1.3 E8 J/gallon)(6.6E4 sej/J)/ ($1 * 2.6 E12 SEJ/$)

3. 1 ton Fertilizer:
(1 ton)(9.07 E5 g/ton)(5.55 E9 sej/g)/($164/ton * 2.6 E12 sej/$) = 11.8

4. 100 pounds Beef:
(100 lb)(454 g/lb)(2.82 kcal/g)(4186 j/kcal)(1.73 E6 sej/J)/($55 * 2.6 E12 sej/$) = 6.5

5. One pound Cotton:
(454 g/lb)(3.7 kcal/g)(4186 J/kcal)(8.6E5 sej/J)/($.59 * 2.6 E12 sej/$) =
= 3.9

6. 1 bushel wheat:
(27.2 E3 g/bushel)(3.3kcal/b)(4186 J/kcal)(8.6E4 sej/J)/($3.55 * 2.6 E12 sej/$) = 3.5

7. One pound Wool:
(454 g/lb)(5 kcal/g)(4186 j/kcal)(3.8 E6 sej/J)/($.83)(2.6 E12 sej/$) = 16.7

8. 100 pounds potatoes:
(100 lbs)(454 g/lb)(.22 dry)(4 kcal/g)(4186 J/kcal)(2.6 E5 sej/J)/($8.50 * 2.6 E12 sej/$) = 2.0

In an example of emergy evaluation of agricultural operations, emergy analysis was applied by J. Snoddy (1) to one category of federal agricultural census statistics, Texas farms, ranches, and poultry farms with gross receipts over $100,000. Fundamentally different operations, such as low-energy range cattle operations in West Texas and intensive crop farms in the east were lumped in overall averages (appendix 35).

The emergy of transpired water (250 E12 sej/yr) is the main environmental input and the emergy purchased from the economy (1423 E12 sej/yr) includes a sum of the emergy in fertilizer, fuels, electricity, machinery and equipment, livestock and feeds, and human services (equated with total income) (figure 7.2). The investment ratio (ratio of purchased inputs to free environmental inputs) was 5.6. Although lower than the ratio of 7 for all economic activity in the state, it does indicate that today large-scale agriculture, on the average, is an industrial enterprise.

ADAPTING AGRICULTURE TO A DECLINING ENERGY FUTURE

With the gradual decline of availability of cheap fuel the world over, the recent urban basis of the economy will have to decrease, and agriculture will once again become more and more the mainstay of the economy. The overall economy will benefit from efficiencies in agriculture that replace high emergy purchased inputs with free environmental inputs. Agricultural policies need to recognize these inevitable trends and facilitate the adaptation to more, but low-intensity, agriculture.

Water rights that have been allocated to agriculture should be retained for agriculture where possible, although policies should encourage efficient use. Current pressures to reallocate water for urban use are based on the assumption that urban growth can continue. It is said that water should be allocated to its highest valued use, although that usually means the use for which there is the highest price, or market value. The arguments and emergy calculations in chapter 5 suggest that the large macroeconomic value of water is in agriculture. This productive, rather than consumptive, use of water generates money circulation by supporting agricultural production, which in turn creates jobs throughout the economy as products are processed and finally consumed. Since as much as 24 percent of the economy is somehow dependent upon agriculture, urban jobs will be lost by taking water from agriculture for consumer uses.

Increasingly, agricultural production will compete by eliminating those cost increases caused by rising energy prices. Eliminating fuel taxes stimulates production as discussed in chapter 6. Production for local markets decreases transportation costs. Using small machinery decreases fuel costs and reduces compaction of the soil. Soil and water conservation practices return free inputs from living organisms and organic matter in the soil and increase water and nutrient retention capacity. Increased reliance on natural predators decreases the use of pesticides. Minimizing loans and interest is appropriate when an economy is no longer growing, and land values are not increasing.

AGRICULTURE AS AN ENERGY SOURCE

The net emergy yield ratios for several aspects of Texas agriculture were only slightly larger than one (table 7.2). Because these agricultural crops use almost as much emergy from the economy as they yield to it, these were not an energy source for the economy. Many studies show biomass crops such as sugar cane and plantation forestry to have small net emergy yield ratios of 2 to 3. These crops cannot compete with present fuels which have much higher ratios as discussed in chapter 6. Eventually when fossil fuels are much more expensive, biomass crops will compete.

As oil, gas, and related products become scarcer and more precious, their value as emergy sources will be reduced, and the importance of agriculture as a potential net emergy provider will increase. As oil and gas prices approach their real value, agriculture will have to rely less on these inputs. Fuels, chemical fertilizers, and pesticides will have to be replaced by the use of more land and labor. Land and labor will have to be utilized in a fashion that will increase the efficiency of using environmental inputs so that agriculture will become once again the source of net emergy. Optimum rather than maximum production will be the goal.

POLICIES AND THE FUTURE

As can also be seen from figure 7.2a and table 7.2, the emergy investment ratios for the agriculture sector are between 1.3 and 9.6. The overall average is noticeably lower than the investment ratio for the nation as a whole and industry generally, which hovers at about 7. Without further analysis, it is difficult to draw specific conclusions about these ratios, but it is clear that Texas agriculture, if it openly competed for resources with other sectors, would attract a much higher level of investment. (It must again be noted that the range of investment ratios could be fairly large among specific operations, and this conclusion begs further research. If some agriculture is as input-intensive as one would expect, there may be a great deal of underinvestment being encouraged in other sectors.)

National policy, by applying subsidies to keep agricultural prices low, may well ensure that returns to labor and/or land are artificially low. This would account for a lower than expected investment ratio and could explain the current farm crisis, especially the loss of almost 8,000 farm families from the sector last year and the collapse of many farm banks. While the whole economy must adjust to declining emergy per capita in this country, the difference in emergy investment now may be reducing the efficiency of agriculture, encouraging the use of soil and water resources and reducing urban enterprises and employment related to agriculture production. Again, further research is suggested.

The investment ratio is a useful index for determining which sectors of agriculture are economical and appropriate at a given time. As the national investment ratio that is competitive for all economic activity gradually decreases, costs, including wages, have to come down, a trend already observed in many industries.

A lower investment ratio in agriculture dictates using more labor and less machinery and provides an opportunity for more jobs. Since agriculture in Texas already has low wages and low costs (low investment ratio), it may be able to intensify its production considerably, even increasing its wage rates, and still be competitive. Providing high emergy of land (for gardens and on-site living) for farm labor can increase standards of living and improve initiatives without greatly increasing costs.

However, agricultural policies, such as acreage limitations, that encourage such high intensity farming may delay the cost reductions required as the investment ratio declines. More land should be used, not less. Subsidies could be tied to the investment ratio.

As fuel costs rise, making long distance tranport too expensive, Texas agriculture can readily compete against foreign imports for domestic markets. Keeping agricultural produce for home consumption rather than export is a net emergy benefit to the economy. These trends suggest the potential for agricultural prosperity in Texas in years to come.

ENDNOTES

(1) Snoddy, J. "Farm Size and Agricultural Change." Unpublished student report for Policy Research Project course, The University of Texas at Austin, LBJ School of Public Affairs, 1986, pp. 216-234.

TECHNICAL APPENDIX

for

ECOLOGY AND ECONOMY:
EMergy Analysis and Public Policy in Texas
H.T. Odum, E.C. Odum, et al.

These are the calculation tables, footnotes, and references for the shorter tables and text conclusions in the main report. Definitions and explanations of the calculations are given in the Methods Section of the main report. Some references are cited in these tables and others are given in a list at the end of each chapter group.

Many of these appendices are emergy analysis evaluations of flows and storages. In these tables raw data are multiplied by solar transformities to obtain the solar emergy of the item.

Solar transformity is the solar energy required directly and indirectly to generate one unit of energy of the item. It is measuried in solar emjoules per joule, abbreviated sej/J.

Solar emergy is the solar energy required directly or indirectly to generate the item. It is measured in solar emjoules, abbreviated sej.

Then the emergy is divided by the emergy per dollar ratio to obtain the macroeconomic value, which is the dollar contribution that item makes directly or indirectly to the gross economic product. This is usually larger than regular economic value, which is what people pay for the human services involved in the item. One kind of value should not be used for the other.

Appendix 1

Evaluation of the Resource Basis of the U.S.A. in 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (E9 1983 US$)
RENEWABLE SOURCES:					
1	Sunlight	4.48E22 J	1/J	4.48	18.66
2	Rain, chemical	4.17E19 J	15444/J	64.40	268.33
3	Rain, geopotential	6.33E19 J	8888/J	56.21	234.21
4	Wind, kinetic	1.63E20 J	663/J	10.80	45.02
5	Waves	1.09E19 J	25889/J	28.22	117.57
6	Tide	7.63E18 J	23564/J	18.0	74.91
7	River water				
8	Earth cycle	1.36E19 J	29000/J	39.44	164.33
9	Hydroelectricity	1.19E18 J	1.59E5/J	18.92	78.83
10	Wood consumption	4.41E18 J	34900/J	15.39	64.12
IMPORTS AND OUTSIDE SOURCES:					
11	Natural gas	1.01E18 J	48000/J	4.84	20.2
12	Oil,crude	7.63E18 J	53000/J	40.43	168.49
13	Petroleum products	3.95E18 J	66000/J	26.07	108.62
14	Iron & steel products	1.78E7 T	1.78E15/T	3.16	13.20
15	Iron ore	1.32E13 g	8.55E8/g	1.12	4.70
16	Aluminum ore (bauxite)	7.5E12 g	8.5E14/T	0.64	2.67
17	Goods and services	3.65E11 $	3.8E12/$	138.70	577.91

Appendix 1 (continued)

Evaluation of the Resource Basis of the U.S.A. in 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (E9 1983 US$)
NONRENEWABLE SOURCES FROM WITHIN U.S.A.:					
18	Iron ore production	3.76E13 g	3.55E8/g	3.21	13.39
19	Coal production	2.49E19 J	39800/J	99.10	412.92
20	Coal consumption	2.34E19 J	39800/J	93.13	388.05
21	Oil production	2.36E19 J	53000/J	125.08	521.16
22	Oil consumption	3.49E19 J	53000/J	184.97	770.70
23	Natural gas production	1.76E19 J	48000/J	84.48	352.
24	Natural gas use	1.85E19 J	48000/J	88.8	370.
25	Uranium production	6.52E18 J	1790/J	1.16	4.86
26	Electricity use	8.82E18 J	1.59E5/J	132.28	551.2
27	Nuclear electric use	1.05E18 J	1.59E5/J	16.69	69.56
28	Phosphate fert. prod.	2.84E12 g	2E10/g	5.68	23.66
29	Phosphate rock produc.	1.15E13 g	1.4E10/g	16.1	67.08
30	Bauxite production	8E11 g	8.55E8/g	0.06	0.28
31	Bauxite consumption	8.8E12 g	8.55E8/g	0.75	3.13
32	Earth loss	5.87E14 g	1.71E9/g	100.37	418.32
33	Net topsoil produc.	2.1E18 J	62500/J	13.12	54.68

Sources:

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Energy Information Administration/Department of Energy (EIA/DOE). Petroleum Supply Monthly. June, 1985b.

Energy Information Administration/Department of Energy (EIA/DOE). Weekly Coal Production. August 10, 1985.

National Geographic. Atlas of the World, Fifth Edition. Washington, D.C.: National Geographic Society.

Sclater, J.F., G. Taupart, and I.D. Galson. "The heat flow through the orceanic and continental crust and the heat loss of the earth." Rev. of Geophysics and Space Physics 18:269-311. 1980.

Swaney, D.F. Energy Analysis of Climatic Inputs to Agriculture. M.S. Thesis, Environmental Sciences, University of Florida, Gainesville. 1978.

U.S. Coastal and Geodetic Survey. Wave Height Tables. Washington, D.C.: U.S. Department of Commerce. 1956.

U.S. Department of Commerce. Statistical Abstract of the United States 1984. Washington, D.C. 1985.

Notes: Total area: 9.4 E12 m^2. To calculate macroeconomic value, emergy flow in column 3 was divided by 2.4 E12 solar emjoules/$ for U.S. in 1983.

1. Sunlight: total area: 9.4E12 m^2, Alaska: 1.53E12 m^2; continental shelf: total: 1.7E12 m^2, Alaska: 1.07E12 m^2 estimated (National Geographic, 1981) 48 states av. net absorbed solar radiation 110 kcal/cm^2/y.

(8.5E12m^2 without Alaska)(110kcal/cm^2/y)(1E4cm^2/m^2)(4186J/kcal) = 3.9E22J/y

Alaska, 35% albedo; solar radiation absorbed 65% of 3.35E9 J/m^2/y (Budyko, 1963).

(2.6E12m^2)(2.18E9J/m^2/y) = 0.57E22 J/y

Total: 4.48 E22 J/y

2. Rain, chemical potential energy. Average 35.4 in/y from mean of 50 values, each a median for one of the 50 states.

(9.4E12m^2)(35.4in)(2.54cm/in)(1E-2m/cm)(1E6g/m^3)(4.94J/g) = 4.17E19 J/y

3. Rain, geopotential energy. Mean elevation, 763 m; mean rainfall, 0.9 m.

(9.4E12m^2)(0.9m/y)(1E3kg/m^3)(9.8m/s^2)(763m) = 6.33E19 J/y

4. Wind, kinetic energy. Mean of 25 stations in U.S. (Swaney, 1978).
Eddy diffusion coefficients: January 22.3 m^2/s, July 3.6 m^2/s;
Velocity gradients: January 6.08E-3m/s/m, July 1.78E-3m/s/m

Winter:
(1E3m)(1.23kg/m^3)(22.3m^2/s)(1.577E7s/0.5y)(6.08E-3m/s/m)^2(9.4E12m^2) = 1.50E20J/0.5y

Summer:
(1E3m)(1.23kg/m^3)(23.6m^2/s)(1.577E7s/0.5y)(1.78E-3m/m/m)2(9.4E12m^2) = 0.135E20J/0.5y

Total: (1.50 + 0.135)E20 J/y = 1.63E20 J/y

5. Waves. Continental straight coastline: 6.4E6m est. (National Geographic, 1981); Alaska N + W: 1.97E6m; Alaska S + Aleutians: 1.07E6m.
Wave power: av. U.S.: 40.5kw/m; N. Pacific for S Alaska: 81kw/m.
Cont. USA: (40.5kw/m)(1E2w/kw)(1J/s/w)(3.15E7s/y)(6.46m facing shore) = 8.18E18 J/y
South Alaska: (81kw/m)(1E3w/kw)(1J/s/w)(3.154E7s/y)(1.07E6m) = 2.7E18 J/y
Total waves: (8.18E18J/y) + (2.7E18J/y) = 1.09E19 J/y

6. Tide. USA continental shelf: 6.38E11m^2, Alaska cont. shelf: N + W, 3E17m^2;

S shelf: 1.29E17m^2 estimated (National Geographic, 1981); tide height, continental USA: 1.2m averaged(US Coastal and Geodetic Survey, 1956).
Continental: (6.38E11m^2)(0.5)(706/y)(1.2m)^2(9.8m/s^2)(1.025E3kg/m^3)(0.1) = 3.26E17 J/y
S. Alaska: (1.29E11m^2)(0.5)(706/y)(4m)(2(9.8m/s^2)(1.025E3kg/m^3)(0.1) = 7.3E18J/y

7. River water, elevated rivers.

8. Earth cycle. US surface area assigned heat flows based on ages, following method and data of Sclater et al. (1980). 20%, 2E6J/m^2; 40%, 1.5E6J/m^2/y; 25%, 1.2E6J/m^2/y; 15%, 1E6J/m^2/y.

(9.4E12m^2)(1.45E6J/m^2/y) = 1.36E19 J/y

9. Electricity, hydro. 1983: 3.32E11kWh (EIA/DOE, 1984b, 22).

(3.32E11kWh/y)(3.606E6J/kWh) = 1.20E18J/y

10. Wood consumption. 1983: 14660E6 ft^3/y. (US, 1985).

(14,660E6ft^3/y)(2.7E-2m^3/ft/)(0.7E6g/m^3)(3.8kcal/g)(4186J/kcal) = 4.41E18J/y

11. Natural gas imports. 1983: (9.2E8 tcf)(1.1E9 J/tcf) = 1.01E16 J, 4.64$/tcf (EIA/DOE, June 1985a 7-9).

(9.2E8 tcf)(4.64 $/tcf) = 4.3E9 $/y.

12. Crude oil imports. 1983: 3.33E6 bbl/d * 365.24 = 1.216E9bbl/y; 28.99$/bbl (EIA/DOE, June 1985b, 2-3).

(1.216E9 bbl/y)(6.28E9 J/bl) = 7.64E18 J/y
(1.2E9 bl)(28.99 $/bbl) = 34.8E9 $/y.

13. Petroleum products imports. 1983: 6.289 bbls/y * 6.28E9 J/bbl = 3.949E18 J, 28.99$/bl (EIA/DOE, 1984c, 17).

(6.29E8 bl)(28.99 $/bbl) = 18.3E9 $/y.

14. Iron and steel products imports. 1983: 17.8E6 T, 7.1E9 $ (US, 1985, 702).

15. Iron ore imports. 1983: 13.2E6 T, .446E9 $ (US, 1985, 713).

16. Bauxite (aluminum ore) imports. 1983: 7.5E6 T (US, 1985, 716); 29.17$/T (US, 1985, 473).

17. Goods and services imports. 1983: 365E9$ (US, 1985, 800).

18. Iron ore production. 1983: 37.6E6T (US, 1985, 713).

19. Coal production. 1983: 785E6 short T (EIA/DOE, August 10, 1985, 4-9).

(78E6sT/y)(3.18E10J/sT) = 2.49E19J/y

20. Coal consumption. 1983: 736.67E6 short tons (EIA/DOE, August 10, 1985, 4-9).

(736.67E6sT)(3.18E10J/sT) = 2.34E19J/y

21. Crude oil production. 1983: 3.76E6bbl (EIA/DOE, 1984c, 16).

(3.76E6bbl)(6.28E9J/bbl) = 2.36E19J/y

22. Crude oil consumption. 1983: 15.23E6bbl/d (EIA/DOE, 1984c, 16).

(15.23E6bbl/d)(365d/y)(6.28E9J/bbl) = 3.49E19J/y

23. Natural gas production. 1983: 16.3E15BTU (US, 1985, 554).

(16.3E15BTU)(1054J/BTU) = 1.71E19J/y

24. Natural gas consumption. 1983: 17.4BTU (US, 1985, 554).

(17.4E15BTU)(1054J/BTU) = 1.83E19J/y

25. Uranium production. 1983: 6.51E18J (EIA/DOE, 1984a, 195).

26. Electricity, total. 1983: 2.31E12kWh (EIA/DOE, 1984b, 22).

(2.31E12kWh/y)(3.606E6J/kWh) = 8.32E18J/y

27. Electricity, nuclear. 1983: 2.94E11kWh (EIA/DOE, 1984b, 22).

(2.94E11kWh)(3.606E6J/kWh) = 1.06E18J/y

28. Phosphate fertilizer production. 1983: 8.6E6T, 33% phosphorus (US, 1985).

(8.6E6T)(.33) = 2.84E6T

29. Phosphate rock production. 1983: 46.9E6T, of which 14.4E6T is P2O5. (US, 1985, 711); 66/80, .8 is P in P2O5.

(14.4E6T)(.8) = 11.5E6 T/y

30. Bauxite production. 1983: .8E6T (US, 1985, 716).

31. Bauxite consumption. 1983: 8.8E6T (US, 1985, 716).

Appendix 2

Evaluation of the Storages of the U.S.A. in 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (E9 1983 US$)
1	Phosphate	1.8E14 g	1.4E10/g	253.8	1057.5
2	Coal	1.17E22 J	39800/J	46566.	194025.
3	Natural gas	2.17E20 J	48000/J	1041.6	4340.
4	Uranium	2.95E20 J	1790/J	52.80	220.02
5	Petroleum	1.71E20 J	53000/J	906.3	3776.25
6	Topsoil	7.35E20 J	63000/J	4630.5	19293.75
7	Wood biomass	4.72E19 J	34900/J	164.72	686.36
8	Groundwater	1.88E20 J	41000/J	770.8	3211.66
9	Economic assets	6.6E13 $	2.4E12 $	15840.	66000.
10	Population	7.25E9 peo-y	3.1E16/peop-y	22475.	93645.83

Sources:

Brady, N.C. The Nature and Properties of Soils. New York: MacMillan. 1974.

Slesser, M. Energy in the Economy. New York: MacMillan. 1978.

United Nations (UN) 1978/1980 Statistical Yearbook. New York: United Nations. 1981.

U.S. Department of Commerce. Statistical Abstract of the United States 1982. Washington, D.C. 1983.

U.S. Department of Commerce. Statistical Abstract of the United States 1984. Washingdon, D.C. 1985.

Notes: US area: 9.4 E12 m^2. To calculate macroeconomic value energy flow in column 3 was divided by 2.4 E12 solar emjoules/$ for U.S. in 1983.

1. Phosphate rock: 1.8E9 T (US, 1983); 10% p.

   (1.8E9T)(0.1) = 0.18E9 T

2. Coal: 3.7E11 T, brown coal and lignite: 0.3E11 T (UN, 1981).

   (7E6kcal/T(4186J/kcal)(4.0E11T) = 1.18E22 J

3. Natural gas: 5.7E12m^3 at 9077 kcal/m^3 (UN, 1981).

   (5.7E12m^3)(9077kcal/m^3)(4186J/kcal) = 2.17E20 J

4. Uranium: 5.3E5 T (UN, 1981).

   (5.3E5T)(0.007)(1E6g/T)(7.95E10J/g U235) = 2.95E20 J

5. Crude petroleum: 3.8E9T (UN, 1981); 45E9J/T (Slesser, 1978).

   (3.8E9T)(45E9J/T) = 1.71E20 J

6. Topsoil : farm area, 4.22E12m^2, 11.2T org./A (Brady, 1974); forest and miscellaneous area, 4.79E12m^2, 17.5T/A.

Organic matter:

   (4.22E12m^2)(11.4T/A)(1E6g/T) + (4.79E12m^2)(17.5T/A)(1E6g/T) = 3.25E16 g
   (3.25E16g)(5.4kcal/g)(4186J/kcal) = 7.35E20 J

7. Wood biomass (US, 1983).

8. Groundwater : (US, 1983).

   (9.4E12m^2)(0.05porosity)(100m)(1E6g/m^3)(4J/g) = 1.88E20 J

9. Economic assets. 1983: Gross National Product x 20 (5%/y depreciation: GNP 3305E9$ (US, 1985).

   (330E9$)(20) = 6.6E13 $

10. Population in 1983: 234E6 people; median age 31 (US, 1985).

   (234E6 p)(31 y) = 7.25E9 people-years.

Appendix 3

Evaluation of Exports and Other Flows of the U.S.A. in 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej/y)	Macroeconomic value (E9 1983 US$)
EXPORTS:					
1	Oil	3.76E17 J	53000/J	1.99	8.30
2	Petroleum products	1.32E18 J	66000/J	8.71	36.3
3	Coal	2.48E18 J	39800/J	9.87	41.12
4	Corn	1.9E17 J	68000/J	1.29	5.38
5	Iron & steel products	1.4E6 T	1.78E15/T	0.24	1.03
6	Phosphate rock	3.46E6 T	1.41E16/T	4.89	20.38
7	Phosphate fertilizer	2.18E6 T	2E16/T	4.36	18.16
8	Wood	1.4E18 J	34900	4.88	20.35
9	Nitrogen products	6.75E6 T	4.19E15/T	2.82	11.78
10	Goods and services	3.32E11 $	2.4E12/$	79.68	332.
DOLLAR FLOWS:					
11	Gross national product	3305E9 $	2.4E12/$	793.2	3305.
12	U.S. assets abroad	4.95E10 $	2.4E12/$	11.88	49.5
13	Foreign assets in U.S.	8.17E10 $	2.4E12/$	19.61	81.7

Sources:

Energy Information Administration/Department of Energy (EIA/DOE). Petroleum Supply Monthly. June, 1985b.

Energy Information Administration/Department of Energy (EIA/DOE). Petroleum Supply Annual 1984. Vol. 1. 1984c.

Energy Information Administration/Department of Energy (EIA/DOE). Weekly Coal Production. August 10, 1985.

U.S. Department of Commerce. Statistical Abstract of the United States 1984. Washington, D.C. 1985.

Notes: US area, 9.4 E12 m^2. To calculate macroeconomic value, emergy flow in column 3 was divided by 2.4 solar emjoules/$ for U.S. in 1983.

1. Crude oil exports. 1983: 164E3 bl/d * 365.24 = 5.99E7 bl (EIA/DOE, June 1985b, 2-3).

(5.99E7 bbl)(6.289 J/bl) = 3.76E17 J/y
(5.99E7 bbl)(28.99 $/bl) = 1.7E9$

2. Petroleum products exports. 1983: 5.75 bls/d * 365.24d = 2.10E8 bls (EIA/DOE, 1984c, 17).

(2.1E8 bl)(6.28E9 J/bl) = 1.32E18 J/y

3. Coal exports. 1983: 77.8E6 short tons (EIA/DOE, August 10, 1985, 4-9).

(77.8E6 st)(3.18E10 J/st) = 2.48E18 J/y
(77.8E6 T)(35.50 $/T) = 2.76E9 $/y.

4. Corn exports. 1982: 49E6 T (US, 1985, 658); 1983: 6.5E9 $ (US, 1985, 820).

(49E6 T)(1E6g/T)(.92kcal/g)(4186J/kcal) = 1.9E17 J/y.

5. Iron and steel products exports. 1983: 1.4E6 T, 1.6E9 $ (US, 1985, 702).

6. Phosphate rock exports. 1983: 4.2E6 T P2O5 (US, 1985, 711); .8 P in P2O5; .327E9 $

(6.2E6 T)(.8) = 3.47E6 T of phosphate

7. Phosphate fertilizer exports. 1983: 6.6E6 T, 89E6$ (US, 1985, 702); 33% P.

(6.6E6T)(.33) = 2.18E6 T/y

8. Wood exports. 1983: 4,700E6 cu ft, wood, rough and shaped 2.88E9 $ (US, 1985, 820).

(4,700E6 cu ft)(2.7E-2m^3/cu ft)(.7E6 g/m^3)(3.8 kcal/g)(4186J/kcal) = 1.4E18 J

9. Nitrogen products exports. 1983: 7.5E6 short tons; 1982: $1.05E9 (US, 1985, 702).

(.9E6 g/sh ton)(7.5E6 sht) = 6.75E12 g/y
(2.1E8 bbl)(28.99 $/bbl) = 6.1E9 $/y.

10. Goods and services exports. 1983: 332E9 $ (US, 1985, 800).

11. Gross national product. 1983: 3305E9 $ (US, 1985, 428).

12. US assets abroad, net ($ out of US). 1983: 49.5E9 $ (US, 1985, 801).

13. Foreign assets in the US, net (money into US). 1983: 81.7E9 $ (US, 1985, 801).

Appendix 4

Summary of Flows for the U.S.A., 1983 (figure 3.2)

Letter in figure 3.2	Item	Solar Emergy (E22 sej/y)	Dollars (E9 $/y)
R	Renewable sources used (rain, tide, etc.)	82.4	
N	Nonrenewable sources flow within the US:	534.6	
	N0 Dispersed rural source	97.6	
	N1 Concentrated use	420.2	
	N2 Exported without use	25.5	
F	Imported fuels and minerals	73.1	
G	Imported goods	6.5	
I	Dollars paid for imports		365.
P2I	Emergy value of goods and services imports	138.7	
I3	Dollars paid for imports minus goods		301.
P2I3	Imported services	114.	
E	Dollars paid for exports		332.
P1E	Emergy value of goods and services exports	73.	
B	Exported products transformed within US	19.	
E3	Dollars paid for exports minus goods		309.
P1E3	Exported services	68.	
X	Gross national product		3305.
P2	World emergy/$ ratio, used for imports	3.8E12 sej/$	
P1	US emergy/$ ratio, used for US and exports	2.4E12 sej/$	

Source:

Odum, H.T. and E.C. Odum. Energy Analysis Overview of Nations. Working Paper WP-83-82. Laxenburg, Austria: International Institute for Applied Systems Analysis. 1983.

Notes:

R. Renewable sources used: rain + tide. 82.4E22 sej/y (table 3.1)

N. Nonrenewable sources: N0 + N1 + N2 = 534.6E22 sej/y.

N0. Dispersed rural sources (table 3.1): earth loss 100E22 sej + soil formation 13E22 sej - wood consumption 15.39E22 sej = 97.6E22 sej/y

N1. Concentrated use. 1983 (table 3.1): E22sej/v : Oil 185 + coal 93.1 + gas 88.8 + nuclear electricity 16.69 + hydroelectriity 18.92 + phosphate fertilizer and rock 12.53 + iron ore 4.33 + bauxite 0.8 = 420.17E22 sej/y.

N2. Exported without use. 1983 (table 3.2): E22sej/y: oil 10.7 + coal 9.87 + phosphate rock 4.89 = 25.5E22 sej/y.
$ in N2: oil 7.8 + coal 2.8 + p rock .33 = 10.9E9 $/y.

F. Imported minerals and fuels. 1983 (table 3.1): E22 sej/y: oil 66.5 + gas 4.8 + iron ore 1.1 + bauxite .6 = 73.0E22 sej/y.
$ in F: E9$: oil and products 52.2 + gas 4.3 + iron ore 0.45 + bauxite 0.22 = 58.17E9 $/y.

G. Imported goods. 1983: iron and steel products 3.2E22 sej/y.
$ in G: E9$: 7E9$/y.

I. Dollars paid for imports. 1983: 365E9 $(table 3.1).

P2I. Emergy value of goods and services imports. (365E9 $/y)(3.8E12 sej/$) = 138.7E22 sej/y.

I3. Dollars paid for imports minus dollars in goods (G) and minerals and fuels (F). 1983: 365 - 64 = 301E9 $.

P2I3. Imported services minus those in F and G. 1983: (3.8E12 sej/$)(301E9 $) = 114E22 sej/y

E. Dollars paid for exports. 1983: 332E9 $/y (table 3.2)

P1E. Emergy value of goods and services exports. (332E9 $/y)(2.2E12 sej/$) = 73E22 sej/y.

B. Exported products transformed within the country. 1983(table 3.2):
E22sej/y: phosphate fertilizer 4.4 + corn 1.3 + iron and steel products 0.25 + nitrogen products 2.8 + wood 4.9 = 13.7E22 sej/y
$ in B: E9$: fertilizer 0.9 + corn 6.5 + iron & steel 1.6 + nitrogen 1.05 + wood 2.88 = 12.93E9 $/y

E3. Dollars paid for exports minus dollars in goods (B) and raw exports (N2). 1983: 332E9$ - 23E9$ = 309E9 $/y.

P1E3. Exported services. 1983: (2.2E12 sej/$)(309E9 $/y) = 68.0E22 sej/y.

X. Gross national product. 1983: 330E9 $/y.

P2. Ratio of emergy to dollar of imports :world 1980 (Odum and Odum, 1983): 3.8E12sej/$.

P1. Ratio of emergy to dollar of US and its exports. 1983: 2.4E12 sej/$.

Appendix 5

Indices using emergy for Overview of the U.S.A. in 1983 (table 3.4)

Item	Name of index	Expression	Quantity
1	Renewable emergy flow	R	82.4E22 sej/y
2	Flow from indigenous nonrenewable reserves	N	534.6E22 sej/y
3	Flow of imported emergy	F+G+P2I3	193.6E22 sej/y
4	Total emergy inflows	R+N+F+G+P2I3	810.6E22 sej/y
5	Total emergy used, U	N0+N1+R+F+G+P2I3	785.1E22 sej/y
6	Total exported emergy	B+P1E3	87.0E22 sej/y
7	Fraction of emergy used derived from home sources	(N0+N1+R)/U	0.76
8	Imports minus exports	(F+G+P2I3)-(N2+B+P1I3)	84.1E22 sej/y
9	Ratio of exports to imports	(N2+B+P1E3)/(F+G+P2I3)	0.57
10	Fraction used, locally renewable	R/U	0.10
11	Fraction of use purchased	(F+G+P2I3)/U	0.25
12	Fraction used, imported service	P2I/U	0.18
13	Fraction of use that is free	(R+N0)/U	0.22
14	Ratio of concentrated to rural	(F+G+P2I3+N1)/(R+N0)	3.4
15	Use per unit area (9.4E12 m2)	U/(area)	8.4E11 sej/m2
16	Use per person (234E6 population)	U/(population)	3.4E16 sej/person
17	Renewable carrying capacity at present living standard	(R/U)(population)	23.4E6 people
18	Developed carrying capacity at same living standard	8(R/U)(population)	187.2E6 people
19	Ratio of use to GNP, emergy/dollar ratio (GNP:3.3E12 $)	P1 = U/(GNP)	2.4E12 sej/$
20	Ratio of electricity to use (El: 132.3E22sej/y)	(el)/U	0.17
21	Fuel use per person (Fuel: 3.43E24 sej)	(fuel)/(population)	1.5E16 sej/person

Appendix 6

Equations for Computer Simulation Model (figure 3.3)

$R = J - k_o RFPW_T \quad \therefore \quad R = J/(1 + k_o FPW_T)$

$R_2 = J_R - M_6 RW_T FP$

$W_T = R_2 + M_9 W$

$\dot{W} = R_2 - k_2 W - k_3 BWAP\ (E_1 + E_2)(k_5 M/P_5) - M_2 RFPW_T$

$\dot{F} = L_8 J_R - k_6 F - k_7 RFPW_T + M_7 A$

$\dot{B} = k_8 RFPW_T - M_8 B - k_9 B - L_1 BWAP\ (E + E_2)(k_5 M/P_5)$

$\dot{M} = P_1 L_5 BWAP(E+E_2)(k_5 M/P_5)+(L_6 GV-P_2 L_6 GV+P_2 N_8 M-N_8 M-k_4 M-k_5 M-L_7 M-N_9 M$

$\dot{E} = -M_4 BWAP(E+E_2)(k_5 M/P_5)$

$E_2 = M_1(k_4 M/P_4)$

$\dot{A} = L_2 BWAP(E+E_2)(k_5 M/P_5)-L_3 A-L_4 AP+L_7 M/P_3+M_3 B-M_5 A$

$\dot{G} = N_2 B + N_3 A - N_5 G$

$\dot{P} = L_9\ (A/P - FA) + N_6 AP - N_7 P$

$P_4 = P_4 + .003(T)$ where T = years after start

Appendix 7

U.S.A. Simulation Program in BASIC for Apple II

```
1  REM    USA3,APPLE VERSION, COPYRIGHT, H.T.ODUM, DECEMBER, 1986
2  REM  UNITED STATES 1983
3  HGR : HCOLOR= 3
4  REM  GRAPH COORDINATES
5  HPLOT 0,80 TO 278,80
6  HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0
10  REM  COEFFICIENT CALCULATIONS FOR USA
20  REM  SCALING FACTORS
21 I = 1
23 T0 = 1
25 B0 = .3
27 W0 = .5
29 A0 = 2
31 P0 = 4
33 M0 = .02
35 G0 = .1
40 E0 = 3
50  REM  OUTSIDE SOURCES
51 J = 1
53 JR = .29
57 V = 1
59 P1 = 1
61 P2 = .1
63 P3 = 1
65 P4 = .17
67 P5 = .05
70  REM  INITIAL STORAGES
72 W = 3.5
74 F = 21
76 B = .1
78 G = 1
80 A = 5
82 P = 20
84 M = .6
88 E = 211
90 R2 = .05
92 R = .1
94 FA = .05
100  REM  STORAGES AND SOURCES FOR CALIBRATION
103 K0 = .0366300366
105 K1 = 0
107 K2 = 5.71428572E - 03
109 K3 = 9.62915733E - 08
111 K4 = .09
112 K5 = 1.66666667E - 03
114 K6 = 2E - 03
118 K7 = 4.07000407E - 03
120 K8 = .0138380138
122 K9 = .12
124 L1 = 2.40728933E - 06
126 L2 = 2.11841461E - 05
```

```
128 L3 = .0216666667
130 L4 = 9.25925926E - 05
132 L5 = 4.82E - 3
134 L6 = .1
135 L5 = 2.8887472E - 06
136 L7 = .5
138 L8 = .144827586
140 L9 = 2.9068323
142 N1 = 0
144 N2 = .02
146 N3 = 1.66666667E - 04
148 N4 = 0
150 N5 = .02
155 N6 = 1.42450143E - 04
157 N7 = 8.54700855E - 03
160 N8 = .0133333333
165 N9 = .0666666667
166 M1 = 311
168 M2 = 8.14000814E - 04
169 M3 = .4
170 M4 = 1.73324832E - 05
171 M5 = 1.83333333E - 03
172 M6 = 9.76800978E - 03
174 M7 = 1.66666667E - 03
175 M8 = .06
176 M9 = 1.42857143E - 03
200  REM  PLOTTING
220  HCOLOR= 1
230  HPLOT T / T0,160 - W / W0
235  HPLOT T / T0,80 - G / G0
240  HCOLOR= 2
250  HPLOT T / T0,160 - B / B0
260  HCOLOR= 3
270  HPLOT T / T0,80 - A / A0
280  HCOLOR= 5
285  HPLOT T / T0,160 - P / P0
290  HCOLOR= 6
293  HPLOT T / T0,160 - E / E0
295  HPLOT T / T0,80 - M / M0
300  REM  EQUATIONS
301 WT = R2 + M9 * W
302 R2 = JR - M6 * R * WT * F * P
303 WT = R2 + M9 * W
305 R = J / (1 + K0 * F * P * WT)
310 E2 = M1 * (K4 * M / P4)
313  IF T = 130 THEN P4 = .2
314  IF T = 144 THEN P4 = .08
315  IF T = 149 THEN P4 = .2
316  IF T < 150 GOTO 318
317 P4 = P4 + .003
318 DW = R2 - K2 * W - K3 * B * W * A * P * (E + E2) * (K5 * M / P5) - M2
     * R * F * P * WT
320 DF =  + L8 * JR - K6 * F - K7 * R * F * P * WT + M7 * A
325 DB = K8 * R * F * P * WT - K9 * B - L1 * B * W * (E + E2) * (L5 * M /
    P5) * A * P - M8 * B
```

```
330 DA = L2 * B * W * (E + E2) * (K5 * M / P5) * A * P + L7 * M / P3 - L3
     * A - L4 * A * P - M5 * A + M3 * B
335 DM = P1 * L5 * B * W * (E + E2) * (K5 * M / P5) + L6 * G * V - P2 * L
    6 * G * V + P2 * N8 * M - N8 * M - N8 * M - K4 * M - K5 * M - L7 * M
     - N9 * M
337 DE =  - M4 * B * W * A * P * (E + E2) * (K5 * M / P5)
340 DG = N2 * B + N3 * A - N5 * G
345 DP = L9 * (A / P - FA) + N6 * P * A - N7 * P
350  REM  NEW VALUES OF STORAGES
352 M = M + DM * I
353  IF M < .0001 THEN M = .0001
355 A = A + DA * I
357  IF A < .01 THEN A = .01
360 W = W + DW * I
365 B = B + DB * I
367  IF B < .001 THEN B = .001
370 P = P + DP * I
375  IF P < .1 THEN P = .1
380 G = G + DG * I
385 F = F + DF * I
387 E = E + DE * I
390 T = T + I
395  REM  GO BACK AND REPEAT FOR THE NEXT TIME INTERVAL
400  IF T / T0 < 279 GOTO 200
500  END
```

Appendix 8

U.S.A. Simulation Program in BASIC for IBM-PC

```
1  REM  USA3 VERSION DECEMBER 1986 COPYRIGHT H.T. ODUM
2  REM  UNITED STATES 1983
3 CLS
4  REM  GRAPH COORDINATES
5 SCREEN 1,0
6 LINE (0,0) - (319,180),3,B
7 LINE(0,60)-(320,60),3
10  REM  COEFFICIENT CALCULATIONS FOR USA
20  REM  SCALING FACTORS
21 T=1
23 T0 = 1
25 B0=.08
27 W0=.2
29 A0 = 2.2
31 P0 = 3
33 M0=.01
35 G0 = .1
40 E0 = 2.5
50  REM  OUTSIDE SOURCES
51 J = 1
53 JR = .29
57 U = 1
59 P1 = 1
61 P2 = .1
63 P3 = 1
65 P4 = .16
67 P5 = .05
70  REM  INITIAL STORAGES
72 W = 3.5
74 F = 21
76 B = .1
78 G = 1
80 A = 5
82 P = 20
84 M = .6
88 E=211
90 R2 = .05
92 R = .1
94 FA = .05
100  REM  STORAGES AND SOURCES FOR CALIBRATION
103 K0 = .0366300366#
105 K1 = 0
107 K2 = .00571428572#
109 K3 = .0000000962915733#
111 K4 = 9.000001E-02
112 K5 = .00166666667#
114 K6 = .002
118 K7 = .00407000407#
120 K8 = .0138380138#
122 K9 = .12
124 L1 = .00000240728933#
126 L2 = .0000211841461#
128 L3 = .0216666667#
```

```
130 L4 = .0000925925926#
132 L5 = .004L6 = .1
135 L5 = 00166666667#
148 N4 = 0
N9 = .0666666667#
166 M6 = .00976800978#
174 M7 = .00166666667#
1 PSET (T / T0,60 - A / A0
300  REIF T = 130 P4=P4 +.007
DF =  + L8 * DB = K8 * R *DA = L2 * B * W DM = P1 * LDE =  - M4 * B *   NEW VALU
ES P = P + DP * T
```

Appendix 9

Evaluation of the Resource Basis of the Texas Economy in 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (E9 1983 US$)
RENEWABLE SOURCES:					
1	Sunlight	3.48E21 J	1/J	0.34	1.42
2	Rain, chemical	2.23E18 J	15444/J	3.44	14.33
3	Rain, geopotential	2.29E18 J	8888/J	2.03	8.46
4	Wind	2.0 E19 J	623/j	1.25	5.2
	Hurricanes	5.7 E15 j	4.1 E4/J	0.023	0.095
5	Waves	2.3E17 J	25889/J	0.59	2.46
6	Tide	4.45E16 J	23564/J	0.10	0.42
7	Irrigation water	7.7 E16 J	1.54 E4/J	0.12	0.50
8	Geologic uplift	7 E17 J/yr	2.9 E4/J	2.0	8.3
9	Hydroelectricity	1.1E16 J	1.59E5/J	0.18	0.75
10	Agricultural production	-	-	8.90	37.08
IMPORTS AND OUTSIDE SOURCES:					
11	Coal	3.53E17 J	39800/J	1.40	5.83
12	Oil	3.67E18 J	53000/J	19.45	81.04
13	Oil from Mexico	1.2E17 J	53000/J	0.63	2.63
14	Organic chemicals	1.07E7 T			
15	Steel goods	1.3E6 T	1.35E15/T	0.17	0.71
16	Aluminum ore	1.7E6 T	8.5E14/T	0.14	0.58
17	Goods and services	6.21E10 $	2.4E12/$	14.90	62.10
18	Net immigration	7.5E6 Peo-yr	3.4E16/Person	25.50	106.25
19	Tourists	28.E9 $	2.4E12/$	6.72	28.

Appendix 9 (continued)

Evaluation of the Resource Basis of the Texas Economy in 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value* (E9 1983 US$)
	NONRENEWABLE SOURCES FROM WITHIN TEXAS				
20	Lignite production	4.67E17 J	37400/J	1.74	7.25
21	Lignite & coal use	8.2E17 J	39800/J	3.26	13.58
22	Oil production	5.67E18 J	53000/J	30.05	125.21
23	Oil use	4.61E18 J	53000/J	24.43	101.79
24	Natural gas production	6.53E18 J	48000/J	31.34	130.58
25	Natural gas use	3.56E18 J	48000/J	17.08	71.17
26	Electricity production	7.44E17 J	1.59E5/J	11.82	49.25
27	Electricity use	7 E17 J	1.59E5/J	11.13	46.38
28	Top soil loss in use	5.2 E17 J	6.3 E4/J	3.28	13.67

Sources:

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Notes: State area: land 7 E11 m^2; Continental shelf & bays, 0.56 E11 m^2; total, 7.56 E11, m^2. To calculate macroeconomic value, emergy flow in column 3 is divided by 2.4 solar emjoules/$ for U.S. in 1983.

1. Sunlight: Solar Transformity = 1 by definition. Radiation 170 kcal/cm^2/y; albedo 0.3 (Odum et al.,1985.); state 7E11m^2

(170kcal/cm^2/y)(E4cm^2/m^2)(7E11m^2)(.7)(4186J/kcal) = 3.49E21J/y

2. Rain, chemical potential energy. 366,600E3 acre-feet/y; 1 acre-ft=1233m^3; 1g/cm^3; 4.94J/g; 1000kg/m^3

(3.66E8 acre-ft/y)(1233m^3/acre-ft)(1E3kg/m^3)(4.94E3J/kg) = 2.23E18 J/y

3. Rain, geopotential energy. 366,600E3 acre-feet rain/year; average elevation: 1700ft.

(3.66E8 acre-ft)(1233 m^3/acre-ft) = 4.51E11m^3
(1700ft)(0.3048m/ft) = 518.16m
(4.51E11m^3)(1E3g/m^3)(518.16m)(9.8m/sec^2) = 2.29E18J

4. Wind energy transferred into lower 1,000 m:
eddy diffusion, 21 M^3/M^2/sec; vertical gradient, 5.9 E-3 m/sec/m
(1000m)(1.23 kg/m^3)(3.154 E7 sec/y)(21 m^3/m^2/sec)(5.9E-3 m/sec/m)(5.9E-3) m/sec/m)(7 E 11 m^2) = 2.0 E19 J/yr

Hurricanes frequency on coast, 5 every 8 years(Bomar, 1983); Energy per hurricane, 4.85 kcal/m^2/day (Hughes, 1952); 3% kinetic energy; 10% energy dispersed to the surface system; duration 1 day. Energy per year:
(5/8)(4.85 E5 kcal/m^2/day)(7.5 E8 m^2)(0.03)(0.10)(2 days)(4186) J/yr
= 5.7 E15 sej/yr

5. Waves. Shoreline 367 mi. = 5.87E5 meters
2.3E 17 J/y

6. Tide. Continental shelf average width. 88.5km

(5.87E5m)(88.5E3m) = 5.02E10m^2 shelf.
(5.02E10m^2)(0.5)(706/y)$(0.5)^2$(1.025E3 kg/m^3)(9.8 m/sec^2)(4.45E16J/y)(1000) = 4/45E16K/y

7. River water, elevated rivers entering Texas, Rio Grande, Canadian, Pecos, Rita Blanca

Irrigation water, 12.7 E6 acre-feet/yr (Texas Dept. of Water Resources, 1985)
(12.7 E6 acre-ft)(4.05 E3 m^2/acre)(0.3 m/ft)(1 E6 g/m^3)(5 J/g) =7.7E16 J

8. Water driven part of geologic cycle

$(3.73\ E10\ m^3/yr)(100?g/m^3\ sediment)/(7\ E11\ m^2) = 5.3\ g/m^2/yr$

With density $2.0 g/cm^3$, the earth cycle rate =

$(5.3\ g/m^2/Yr)/(2.0\ g/cm^3)/(1E4\ cm^2/m^2) = 2.67\ E{-4}\ cm/yr\ (0.27\ cm/1000yrs)$

which is much less than the average earth cycle (2.4 cm/1000 y).

Weathering of soft sedimentary rocks to produce soil clay materials may be keeping up with erosion so that there is little net loss of soil clay storages. Sediment from high erosion rates on the west may be mainly redeposited within Texas.

Since steady state cycle is slow, heat flow from earth is small = 1.0 E6 $J/m^2/y$

$(1\ E6\ J/m^2/yr)(7E11\ m^2) = 7\ E17\ J/yr$

9. Hydroelectricity use. 1982: 11E12 BTU (U.S. Dept. of Commerce, 1984, 555).

10. Agricultural production. 1983: (table 4.2)

11. Coal imports. 1983: coal use minus production.

8.2E17J - 4.67E17J = 3.53E17J

12. Oil imports. 1983: foreign 324.1E6 bbl + domestic 261.5E6 bbl = 585.6E6 bbl (Texas Railroad Commission, Jan.-Dec. 1983.)

(585.6E6 bbl)(6.28E9J/bbl) = 3.67E18J

13. Mexican oil imports to US. 1985: Mex exports 1.5E6 bbl/day, 1/2 to US: light $28.35/bbl, heavy $23.10 bbl.(American-Statesman, November 30, 1985.)

(1.5E6/2)(365) = 2.74E8bbls/y

(2.74E8ffl/y)(5.6E6BTU/bbl)(1054J/BTU) = 1.62E18J

14. Organic chemicals imports (benzene and toluene, naptha, basic chemicals), foreign and domestic through Texas ports. 1983: 107E5T (Dallas Morning News, 1985, 640.)

15. Iron and Steel shapes imports, foreign and domestic through Texas ports. 1983: 1.3E6T (Dallas Morning News, 1985, 640.).

16. Aluminum ore imports, foreign and domestic through Texas ports: 1983 17E5T (Dallas Morning News, 1985, 640.).

17. Goods and services imports. 62.1E9$ (HTO estimated total inflow of money is balanced with outflow for goods and services, table 4.7)

18. Net immigration. 1982: 300,000 people (Dallas Morning News, 1985, 568.) * average age 25 years = 7.5E6 people-years

Transformity: US emergy/person 1980 J/person. 3.1E16 (Odum and Odum, 1983.)

19. Tourist visitors, 40E6 (Austin American-Statesman, May 12, 1986); expenditures and time assumed.

(40E6 visitors)(7 days)($100/day) = $28.E9

20. Lignite production. 1983: 38.9 E6T (EIA/DOE, 1983b, 374.); 12E9J/T (Romer, 1984, 36).
Transformity used 1/2 between wood and coal: 3.74E4 sej/J.

(38.9E6T)(12E9J/T) = 4.67E17J

21. Lignite and coal use. 1983: 68.3E6 short tons (EIA/DOE, 1983b, 374).
Transformity 0.4 lignite: 3.74E4 and 0.6 coal: 3.98E4.

(12E9J/T)(68.3E6T) = 8.20E17J

22. Crude oil production. 1983: 903E6bbls (EIA/DOE, 1983b, 374). 6.28E9J/bbl

(903E6bbls)(6.28E9 J/bbl) = 5.67E18J

23. Oil use. 1983: 734.7E6 bbl (EIA/DOE, 1983b 374). 6.28E9J/bbl

(34.7E6 bbl)(6.28E9 J/bbl) = 4.61E18J

24. Natural gas production. 1983: 5.939E9 tcf; 1.1E9 J/tcf (EIA/DOE, 1983b, 374).

(5.939E9 tcf)(1.1E9 J/tcf) = 6.53E18J

25. Natural gas use. 1983: 3.24E12 cf; 1.1E9 J/tcf (EIA/DOE 1983b, 374).

(3.24E9 tcf)(1.1E9 J/tcf) = 3.56E18J

26. Electricity production. 1983: 206.2E9 KWH (U.S. Dept of Commerce, 1984, 565).

(206.2E9KWH)(3.606E6J/KWH) = 7.44E17J

27. Electricity use. 1983: 191.1E9KWH (U.S. Dept. of Commerce, 1984, 555); 3.606E6J/KWH.

(191.2E9KWH)(3.606E6J/KWH) = 7.0E17J

No Nuclear Electricity on line yet; 2 plants under construction. (U.S. Dept. of Commerce, 1984, 555).

28. Loss of top soil profile in farmed and overgrazed areas:

cropland	33.3 E6 acres	525 E6 T/y
pastureland	17.0 E6 acres	14.6 E6 T/y
rangeland	95.3 E6 acres	177.2 E6 T/y
Forest	9.3 E6 acres	
Grazed		4.1 E6 T/y
Ungrazed		47.4 E6 T/y
Total		768.3 E6 T/y

(768.3 E6 T/yr)(1E6 g/T)(0.03g organic)(5.4 kcal/g)(4186 J/kcal) = 5.2 E17 J/y

Appendix 10

Evaluation of Storages of the Economy of Texas, 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (1983 US $)
1	Population	4.4E8 peop-y	3.1E16/peop-y	1364.	5683.3
2	Economic assets	4.6E12 $	2.4E12/$	1104.	4600.
3	Natural gas	5.9E19 J	48000/J	283.68	1182.
4	Oil and natural gas liquids	6.64E19 J	53000/J	351.92	1466.3
5	Lignite coal	120E18 J	3.74E4/J	44.88	187.
6	Water storage	2.81 E18 J	1.54 E4/J	4.33	18.
7	Topsoil	1.07 E20 J	6.3 E4/J	674.1	2593.

Sources:

Dallas Morning News. Texas Almanac, 1986-1987. 1985.

Texas Department of Water Resources. Annual Statistics. 1984.

Notes: State area: land, 7 E11 m^2; continental shelf and bays, 0.56 E11 m^2; total, 7.56 E11 m^2. To calculate macroeconomic value, emergy flow in column 3 was divided by 2.4 E12 solar emjoules/$ for U.S. in 1983.

1. Population. 1983: 15.7E6 (Dallas Morning News, 1985, 568). * av age 28 (Dallas Morning News, 1985, 442.) = 4.4E8 people-years.

2. Economic assets = gross state product * 20 (5% depreciation per year, estimated by H.T. Odum)

(230E9$)(20) = 4600E9 $

3. Natural Gas . 1983: 50,052E9cf (Dallas Morning News, 1985, 602.); 1.1E6J/cf

(50,052E9cf)(1.1E6J/cf) = 5.91E19J

4. Oil and Natural Gas Liquids. 1983: crude oil 7,539,000E9bbl, nat gas liquids 3,038,000E6bbl (Dallas Morning News, 1985, 602.)

(10,577E6bbl)(6.28E9J/bbl) = 6.64E19J

5. Lignite coal. 1983: 9 - 11 billion short tons (Dallas Morning News, 1985, 608.)
Transformity used 1/2 between wood and coal: 3.74E4 sej/J.

(12E9 J/T)(10E9 T) = 120E18 J

6. 32.3 E6 acrefeet reservoirs; 430 E6 acre feet available groundwater (Texas Department of Water Resources, 1984)
(4.62 E8 Ac ft)(0.3 m/ft)(4.05 E3 m^2/ac)(1 E6 g/m^3)(5 J/g) = 2.81 E18 J/yr

7. Topsoil.

(7 E11 m^2 area)(0.90 soil covered)(0.5 m deep)(0.5 E6 g/m^3)
(.03 organic)(5.4 Cal/g)(4186 J/kcal) = 1.07 E20 J

Appendix 11

Evaluation of Exports and Other Flows in Texas, 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (1983 US $)
EXPORTS:					
1	Oil	4.73E18 J	53000/J	25.06	104.41
2	Natural gas	2.06E18 J	48000/J	9.88	41.17
3	Organic chemicals	2.29E7 T			
4	Grains	7.8E16 J	68000/J	0.53	2.21
5	Electricity	4.4E16 J	1.59E5/J	0.69	2.88
6	Goods and services	4.72E10 $	2.4E12/$	11.33	47.20
DOLLAR FLOWS:					
7	High technology exports	1.93E10 $	2.4E12/$	4.63	19.30
8	Foreign exports	2.25E10 $	3.8E12/$	8.55	35.63
9	Foreign imports	2.81E10 $	2.8E12/$	7.84	32.67
10	Gross state product	2.38E11 $	2.8E12/$	66.64	277.66
11	Federal income taxes	2.2E10 $	2.8E12/$	6.16	25.67
12	Fed transfer payments	3.69E10 $	2.4E12/$	8.86	36.9
13	Rec´d from gas exports	4.86E9 $	2.4E12/$	1.17	4.86
14	Rec´d from oil exports	1.97E10 $	2.4E12/$	4.73	19.70
15	Agricult foreign sales	1.6E9 $	3.8E12/$	0.61	2.53

Appendix 11 (continued)

Evaluation of Exports and Other Flows in Texas, 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (1983 US $)
	AGRICULTURAL PRODUCTION				
16	Cotton	9.6E15 J	1.9E6/J	1.83	7.63
17	Corn	2.65E16 J	6.8E4/J	.18	0.75
18	Wheat	7.33E16 J	6.8E4/J	.50	2.08
19	Grain sorghum	5.84E16 J	6.8E4/J	.40	1.67
20	Cattle	17.2E15 J	2E6/J	3.40	14.17
21	Wool	1.95E14 J	3.8E6/J	0.074	0.31
22	Goods and services	9.0E9 $	2.8E12/$	2.52	10.5
23	Total	-	-	8.90	37.08

Sources:

Albritton, E.C., ed. Standard Values in Nutrition and Metabolism. Philadelphia: W.B. Saunders. 1954.

American-Statesman. Mexican Oil Imports to the United States. November 30, 1985.

Dallas Morning News. Texas Almanac, 1986-1987. 1985.

Energy Information Administration/Department of Energy (EIA/DOE). Electric Power Annual 1983. 1983a.

U.S. Department of Agriculture. Agricultural Statistics, 1984. Washington, D.C.

U.S. Department of Commerce. Statistical Abstract of the United States 1983. 1984.

Texas Railroad Commission. Annual Report 1983. 1983.

Texas Railroad Commission. Crude Oil and Products Stocks Refinery Runs for P.A.D. Districts I-IV. Jan-Dec. 1983.

Notes: State area: land 7 E11 m^2; Continental shelf & bays, 0.56 E11 m^2; total, 7.56 E11 m^2. To calibrate macroeconomic value, emergy flow in column 3 was divided by the solar emjoules. For exports to the U.S. the emergy/dollar ratio was 2.4 E12 sej/$. For foreign exports the world emergy/dollar ratio was 3.8 E12 sej/$. For imports the Texas emergy/dollar ratio was 2.8 sej/$.

1. Oil exports. 1983: Imports plus production minus use. Imports 3.67E18J; Production 5.67E18J; Use 4.61E18J.

(5.67E18J + 3.67E18J) - 4.61E18J = 4.73E18J

2. Natural gas exports. 1983: 1.87E9 tcf (Texas Railroad Commission, 1983, 62).

(1.87E9 tcf)(1.1E9J/tcf) = 2.06E18J

3. Organic Chemicals, domestic and foreign by Texas ports (plastic, benzene and toluene, naptha, basic chem, coke pet., liquid sulphur). 1983: 229E5 T (Dallas Morning News, 1985, 640.).

4. Grains, domestic and foreign by Texas ports (wheat, grain sorghum, corn). 1983: 203E5T (Dallas Morning News, 1985, 640.); 134 $/T.

(203E5T/y)(E6g/T)(0.92 kcal/g)(4186 J/kcal) = 7.8E16 J/y
(203E5T)(134$/T) = 2.7E9 $

5. Electricity. 1983: Production minus use; 0.063$ average/kwh (EIA/DOE, 1983a, 112-114.); 3.61E6J/kWh

7.44E17J - 7.0E17J = 0.44E17J
(.44E17J)(/(3.61E6J/kWh)(.063$/kWh) = 0.77E9 $/y

6. Dollars paid for exports. 1983: $ for imports - net federal $ inflow:
$62.1E9$ - 14.9E9$ = 47.2E9 $/y.

7. High Technology Export. 1983 .(American Statesman, Nov. 30, 1985, 1).

8. Foreign exports. 1983: $22,532E6 (Dallas Morning News, 1985, 637).

9. Foreign imports. 1983: $28,115.7E6 (Dallas Morning News, 1985, 637).

10. Gross State Product. 1983: 108822 in 1972 million $ (Plaut, Tully, and Henaff, 1985, 67); 1983 $ are 2.15 times 1972 $ (U.S. Dept. of Commerce, 1984, 468).

(108822E6$)(2.15) = 238E9 $

11. Federal Income Taxes. 1982 (U.S. Dept. of Commerce, 1984, 319.)

12. Federal Transfer Payments. 1982. (U.S. Dept. of Commerce, 1984, 314.)

13. Received from gas exports. 1983: 1.87E9 tcf; $2.6/tcf. (Texas Railroad Commission, 1983, 62.)

(1.87E9tcf)($2.6/tcf) = 4.86E9$

14. Received from oil exports. 1983: 4.73E18J; 6.28E9J/bbl; $26.19/bbl (Texas Railroad Commission, 1983, 374.)

(4.73E18J)/(6.28E9J/bbl)(26.19$/bbl) = 19.7E9$

15. Agricultural Foreign Sales. 1983: $1,679.5E6 (Dallas Morning News, 1985, 613).

16. Cotton. 1983: 2.4E6 bales (Dallas Morning News, 1985, 617); 480 lb/bale (U.S. Department of Agriculture, 1984, V); 4 kcal/g carbohydrate. Transformity used was half between wood and wool: 1.9E6sej/J.

(2.4E6 bales)(480lb/bale)/(2000lb/T)(1E6g/T)(4kcal/g)(4186J/kcal) = 9.6E15J/y

17. Corn. 1983: .25E9$, 136$/T (Dallas Morning News, 1985, 617); 3.52 kcal/g (Albritton, 1954).

(0.25E9$)/(136$/T)(1E6g/T)(3.52kcal/g)(4186J/kcal) = 2.65E16 J/y

18. Wheat. 1983: 161E6 bushels, 3.55$/bu (Dallas Morning News, 1985, 617); 1bu = 27.2kg (U. S. Department of Agriculture, 1984, V).
Used corn transformity.

(161E6 bu)(27.2kg/bu)(1E3g/kg)(4kcal/g)(4186J/kcal) = 7.33E16 J/y

19. Grain sorghum. 1983: 3.15E6 acres, 2,800 lbs/acre (Dallas Morning News, 1985, 617); 3.17 kcal/g (Albritton, 1954).
Used corn transformity.

(3.15E6 acres)(2,800 lbs/acre)/(2,000lbs/T)(1E6g/T)(3.17kcal/g)(4186J/kcal) = 5.84E16 J/y

20. Cattle. 1983: 15E6 head cattle stored, turnover 5/14 per year, 2.72E5g/head (Dallas Morning News, 1985, 623); 2.82 kcal/g (Albrittton, 1954).
Used transformity 2E5 sej/J.

(5/14/y)(15E6 head)(2.72E5 g/head)(2.82kcal/g)(4186J/kcal) = 17.2E15 J/y

21. Wool. 1983: 18.6E6 lbs (Dallas Morning News, 1985, 617); 5kcal/g protein.

(18.6E6 lbs)/(2000 lb/T)(1E6kcal/T)(5kcal/g)(4186J/kcal) = 1.95E14 J/y

22. Goods and services. 1983: total production 9.0E9 $ (Dallas Morning News, 1985, 614).

23. Total does not include services because they are farm services already included in commodity items.

Appendix 12

Summary of Flows for Texas in 1983 (figure 4.2)

Letter in figure 4.2	Item	Solar Emergy (E22 sej/y)	Dollars (E9 $/y)
R	Renewable sources used (rain, tide, waves)	4.1	
N	Nonrenewable sources flow within Texas:	67.5	
	N0 Dispersed rural source	3.3	
	N1 Mineral production	63.3	
	N2 Exported without use	38.4	
F	Imported fuels and minerals	20.9	
F2	Fuels used (F+N1-N2)	45.8	
G	Imported goods	0.17	
I	Dollars paid for imports		62.1
I3	Dollars paid for imports minus goods		44.0
PI3	Imported services	9.6	
PI	Imported services incl services in goods	13.7	
B	Exported products transformed within Texas	1.2	
E	Dollars paid for exports		47.2
E3	Dollars paid for exports minus goods		43.7
PE3	Exported services	10.5	
X	Gross state product		238.0
P	U.S. emergy/$ ratio, used for imports	2.4E12 sej/$	

Notes:

R. Renewable sources used, rain-chemical, tide, waves: 4.1E22 sej/y

N. Nonrenewable sources flow within the country: N0 + N1 = 67.5E22 sej/y.

N0. Dispersed rural source: topsoil loss 3.28E22 sej/y (table 4.1)

N1. Production of fuels and minerals. 1983: E22sej/y: lignite 1.74 + oil 30.05 + natural gas 31.34 + hydroelectricity 0.18 = 63.31E22 sej/y.

N2. Fuels exported without use (from local production and imports). 1983: E22 sej/y: oil 25.06 + natural gas 9.88 = 34.9E22 sej/y (table 4.1) - adjusted natural gas to 13.3 to make total 38.4E22 sej/y to balance in figure 4.2.

F. Imported fuels and minerals. 1983: E22 sej/y: coal 1.4 + oil 19.45 = 20.85E22 sej/y (table 4.1).
$ in F:coal (1.1E7T)(25.3$/T) = .28E9 $/y + oil (5.86E8 bbl)(28.99$/bbl) = 17.0E9$; total = 17.3E9$.

F2. Fuels used (F+N1-N2). 45.76E22 sej/y.

G. Imported goods. 1983: iron and steel 0.17E22 sej/y (table 4.1)
$ in G: (1.3E6 T)(589$/T) = .77E9 $/y.

I. Dollars paid for imports. import $ = $ outflow (including federal income taxes and transfer payments) 62.1E9 $/y (figure 4.2)

I3. Dollars paid for imports minus goods (G), fuels and minerals (F). 1983: 62.1E9$ - F 17.3E9$ - G .77E9$ = 44.0E9$/y.

PI3. Imported goods and services minus services in F and G. 1983: (2.4E12sej/$)(43.6E9$) = 1.05E22sej/y.

PI. Imported goods and services. 1983: (2.4E12sej/$)(62.1E9$/y) = 14.9E22sej/y.

B. Exported products transformed within the state. 1983: grain .53E22sej + electr0.77E22sej = 1.2E22sej/y.

E. Dollars paid for exports. 1983: $ for imports - net federal $ inflow: $62.1E9$ - 14.9E9$ = 47.2E9$/y.

E3. Dollars paid for exports minus goods, fuels and minerals. 47.2E9$ - grain 2.7E9$ - electricity .77E9$ = 43.7E9$/y.

PE3. Exported services. 1983: (43.7E9$)(2.4E12sej/$) = 10.5E22sej/y.

X. Gross state product. 1983: 238E9$/y

P. U.S. Emergy to dollar ratio. 1983: 2.4 E12 sej/$.

Appendix 13

Indices using emergy for Overview of Texas (table 4.4)

Item	Name of index	Expression	Quantity
1	Renewable emergy flow	R	4.1E22 sej/y
2	Flow from indigenous nonrenewable reserves, N	N0+N1	71.0E22 sej/y
3	Flow of imported emergy	F+G+PI3	30.7E22 sej/y
4	Total emergy inflows	R+F2+G+PI3	59.7E22 sej/y
5	Total emergy used, U	N0+R+F2+G+PI3	67.4E22 sej/y
6	Total exported emergy	B+PE3	10.8E22 sej/y
7	Fraction of emergy used derived from home sources	(N0+F2+R)/U	0.79
8	Imports minus exports	(F+G+PI3)-(N2+B+PI3)	-18.5E22 sej/y
9	Ratio of exports to imports	(N2+B+PE3)/(F+G+PI3)	1.6
10	Fraction used, locally renewable	R/U	0.06
11	Fraction of use purchased outside	(2/3F+G+PI3)/U	0.37
12	Fraction used, imported service	PI/U	0.20
13	Fraction of use that is free	(R+N0)/U	0.17
14	Ratio of concentrated to rural	(F2+G+PI3)/(R+N0)	4.7
15	Use per unit area (7E11 m2)	U/(area)	9.6E11 sej/m2
16	Use per person (15.7E6 population)	U/(population)	4.3E16 sej/person
17	Renewable carrying capacity at present living standard	(R/U)(population)	0.94E6 people
18	Developed carrying capacity at same living standard	8(R/U)(population)	7.5E6 people
19	Ratio of use to GSP, emergy/dollar ratio (GSP:238E9 $)	P1 = U/(GNP)	2.8E12 sej/$
20	Ratio of electricity to use (El: 11.13E22sej/y)	(el)/U	0.17
21	Fuel use per person (Fuel: 44.8E22 sej)	(fuel)/(population)	2.9E16 sej/person

Appendix 14

Equations for the Texas Simulation Model (figure 4.3)

R2 = JR - M6*R*F*P*R2 - M2*R2

R2 = JR/(1+M6*R*F*P + M2)

R = J/(1+k0*R2*F*P+N4*W*F*P)

DW =R2 - K2*W - K3*B*W*P*(E1 + E2)*(K5*M/P5) -J1*R*F*P*W

DF = K6*F - K7*R*F*P*R2 + M7*A - J2*R*F*P*W + M3*R*R2*F*P

DB = K8*R*F*P*R2 - K9*B - L1*B*W*P*(E1 + E2)*(K5*M/P5) + J3*R*F*P*W

DM = P1*L5*B*W*P*(E1+E2)*(K5*M/P5) + L6*G*V - P2*L6*G*V + P2*N8*M - N8*M - K4*M - K5*M - L7*M - N9*M + Z*P4*K1*E*A + TR

DE = - Z*M4*B*W*P*(E1 + E2)*(K5*M/P5) - Z*K1*E*A

DA = L2*B*W*P*(E1 + E2)*(K5*M/P5) - L3*A - L4*A*P +L7*M/P3 - M5*A - Z*N1*E*A

DG = N2*B + N3*A -N5*G

DP = L9*(A/P - FA) + N6*A*P - N7*P

E1 = L8*E   IF Z = 1

E2 = M1*(K4*M/P4)   IF Z= 1

Z = 1 after oil use begins

Appendix 15

Texas Simulation Program in BASIC for Apple II

```
1  REM  TEXAS2, H.T.ODUM, MARCH, 1987, APPLE VERSION
2  REM     60 YRS  AGRARIAN; 73 YEARS AT OIL PRICE .03;10 YEARS AT .7; 10 YE
AT .3; THEN PRICE .7 WITH .01 ADDED EACH YEAR UP TO P4 = 4
3  HGR : HCOLOR= 3
4  REM  GRAPH COORDINATES
5  HPLOT 0,60 TO 278,60
6  HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0
7  REM  Set TC as time when oil regime starts.
8  REM   Federal transfer payments (TR) at 30 becoming 20% more than tax aft
60 years
20  REM  SCALING FACTORS
21 I = .5
23 TO = 1.5
25 BO = .1
27 WO = .3
29 AO = 150
31 PO = .5
33 MO = 5
35 GO = .1
40 EO = 110
45 FO = 2
50  REM  OUTSIDE SOURCES
51 J = 1
53 JR = 2.3
57 V = 1
59 P1 = 1
61 P2 = .05
63 P3 = 1
65 P4 = .03
67 P5 = 1
68 FA = 100
69 TR = 1
70  REM  INITIAL STORAGES
72 W = 10
74 F = 1
76 B = 1
78 G = 1
80 A = 300
82 P = .1
84 M = 1
88 E = 10000
90 R2 = .53
92 R = .2
94 TC = 60
100  REM  COEFFICIENTS
103 KO = 9.9E - 4
105 K1 = 1.01E - 5
107 K2 = .05
109 K3 = 1.25E - 6
111 K4 = .256
112 K5 = .016
```

```
114 K6 = .012
118 K7 = .0207
120 K8 = 7.9E - 3
122 K9 = .3
124 L1 = 4.24E - 6
126 LA = 8.75E - 4
127 LB = .565E - 3
128 L3 = 2.17E - 2
130 L4 = 8.58E - 4
132 L5 = 1.44E - 4
134 L6 = 7.5
136 L7 = .82
138 L8 = 0
140 L9 = 1.10E - 3
142 N1 = 2.0E - 5
144 N2 = .1
146 N3 = 2.1739E - 5
148 N4 = 3.5E - 4
150 N5 = .2
155 N6 = 4.15E - 6
157 N7 = .0138
160 N8 = 1.66E - 2
165 N9 = .366
167 M1 = 25.6
168 M2 = 2.5
169 M3 = 2E - 2
170 M4 = 1.69E - 4
171 M5 = 6.52E - 3
172 M6 = 8.9E - 3
174 M7 = 8.9E - 4
175 M8 = 0
178 J1 = 5.9E - 5
180 J2 = 5E - 4
182 J3 = 9.9E - 5
200  REM  PLOTTING
202  REM  ABOVE:IMAGE,GREEN
203  REM          URB.ASSETS,WHITE
204  REM           MONEY,BLUE
206  REM          FUEL,BLUE
207  REM          BIOMASS,PURPLE
208  REM          PEOPLE,RED
220  HCOLOR= 1
230  HPLOT T / TO,160 - W / WO
235  HPLOT T / TO,60 - G / GO
240  HCOLOR= 2
250  HPLOT T / TO,160 - F / FO
260  HCOLOR= 3
270  HPLOT T / TO,60 - A / AO
280  HCOLOR= 5
285  HPLOT T / TO,160 - P / PO
290  HCOLOR= 6
293  HPLOT T / TO,160 - E / EO
295  HPLOT T / TO,60 - M / MO
297  REM  EQUATIONS
```

```
 298  IF T < TC THEN L8 = .1
 299  IF T > TC THEN L8 = 1:Z = 1
 300 E1 = L8 * E
 302 R2 = JR / (1 + M6 * R * F * P + M2)
 304 TR = 30 + Z * 1.2 * N9 * M
 305 R = J / (1 + K0 * F * P * R2 + N4 * F * P * W)
 306 L2 = LA + Z * LB
 308 E2 = M1 * (K4 * M / P4)
 309  IF T > 155 GOTO 313
 310  IF T < 133 THEN P4 = P4 + .001
 311  IF T > 133 THEN P4 = .7
 312  IF T > 143 THEN P4 = .3
 313  IF T > 153 THEN P4 = .7
 314  IF T > 155 THEN P4 = P4 + .01
 315  IF P4 > 4 THEN P4 = 4
 316  REM  CHANGE EQUATIONS
 318 DW = R2 - K2 * W - K3 * B * W * P * (E1 + E2) * (K5 * M / P5) - J1 * R * F
* P * W
 320 DF =  - K6 * F - K7 * R * F * P * R2 + M7 * A - J2 * R * F * P * W + M3 *
 * R2 * F * P
 325 DB = K8 * R * F * P * R2 - K9 * B - L1 * B * W * (E1 + E2) * (K5 * M / P5)
* P + J3 * R * F * P * W
 330 DA = (L2 * B * W * (E1 + E2) * (K5 * M / P5) * P) + L7 * M / P3 - L3 * A -
L4 * A * P - M5 * A - Z * N1 * E * A
 335 DM = (P1 * L5 * B * W * P * (E1 + E2) * (K5 * M / P5)) + L6 * G * V - P2 *
L6 * G * V + P2 * N8 * M - N8 * M - K4 * M - K5 * M - L7 * M - N9 * M + Z * P4
 K1 * E * A + TR
 337 DE =  - Z * M4 * B * W * P * (E1 + E2) * (K5 * M / P5) - Z * K1 * E * A
 340 DG = N2 * B + N3 * A - N5 * G
 345 DP = L9 * ((A / P) - FA) + N6 * P * A - N7 * P
 350  REM  NEW VALUES OF STORAGES
 352 M = M + DM * I
 353  IF M < .0001 THEN M = .0001
 355 A = A + DA * I
 357  IF A < .01 THEN A = .01
 360 W = W + DW * I
 362  IF W < .0001 THEN W = .0001
 365 B = B + DB * I
 367  IF B < .00001 THEN B = .00001
 370 P = P + DP * I
 375  IF P < .1 THEN P = .1
 380 G = G + DG * I
 385 F = F + DF * I
 386  IF F < .0001 THEN F = .0001
 387 E = E + DE * I
 388  IF E < 1 THEN E = 1
 390 T = T + I
 395  REM  GO BACK AND REPEAT FOR THE NEXT TIME INTERVAL
 400  IF T / TO < 279 GOTO 200
 500  END
```

Appendix 16

Texas Simulation Program in BASIC for IBM-PC

```
0  CLS
1  REM    TEXAS SIMULATION, COPYRIGHT, H.T.ODUM, MARCH 1987
2  REM   60 YRS  AGRARIAN; 73 YEARS AT OIL PRICE .03;10 YEARS AT .7; 10 YEARS AT
 .3; THEN PRICE .7 WITH .01 ADDED EACH YEAR UP TO 4
3 SCREEN 1,0: COLOR 0,1
4  REM  GRAPH COORDINATES
5 LINE (0,60)-(320,60),3
6 LINE (0,0)-(320,180),3,B
7 REM set TC for start of oil regime
8  REM  Federal transfer payments (TR)   at 30 becoming 10% more than tax at 60
years
20  REM  SCALING FACTORS
21 I = .5
23 TO = 1.5
25 BO = .1
27 WO = .3
29 AO = 150
31 PO = .5
33 MO = 5
35 GO = .1
40 EO = 110
45 FO = 2
50  REM  OUTSIDE SOURCES
51 J = 1
53 JR = 2.3
57 V = 1
59 P1 = 1
61 P2 = .05
63 P3 = 1
65 P4 = .03
67 P5 = 1
68 FA = 100
69 TR = 30
70  REM  INITIAL STORAGES
72 W = 10
74 F = 1
76 B = 1
78 G = 1
80 A = 300
82 P = .1
84 M = 1
88 E = 10000
90 R2 = .53
92 R = .2
94 TC = 60
100  REM  COEFFICIENTS
103 KO = .00099
105 K1 = .0000101
107 K2 = .05
109 K3 = 1.25E-06
111 K4 = .256
112 K5 = .016
114 K6 = .012
```

```
118 K7 = .0207
120 K8 = .0079
122 K9 = .3
124 L1 = 4.24E-06
126 LA = .000875
127 LB = .000565
128 L3 = .0217
130 L4 = .000858
132 L5 = .000144
134 L6 = 7.5
136 L7 = .82
138 L8 = 0
140 L9 = .0011
142 N1 = .00002
144 N2 = .1
146 N3 = 2.1739E-05
148 N4 = .00035
150 N5 = .2
155 N6 = 4.15E-06
157 N7 = .0138
160 N8 = .0166
165 N9 = .366
167 M1 = 25.6
168 M2 = 2.5
169 M3 = .02
170 M4 = .000169
171 M5 = .00652
172 M6 = .0089
174 M7 = .00089
175 M8 = 0
178 J1 = .000059
180 J2 = .0005
182 J3 = .000099
200  REM  PLOTTING
202  REM  ABOVE:IMAGE,upper blue
203  REM        URB.ASSETS,upper white
204  REM        MONEY,upper BLUE
206  REM        FUEL, lower red
207  REM        FARMS, lower red
208  REM        PEOPLE, lower white
230  PSET (T / T0,180- W/W0),1
235  PSET (T / T0,60 - G / G0),1
250  PSET (T / T0,180 - F / F0),2
270  PSET (T / T0,60 - A / A0),3
285  PSET (T / T0,180 - P / P0),3
293  PSET (T / T0,180 - E / E0),2
295  PSET (T / T0,60 - M / M0),2
297  REM  EQUATIONS
300  IF T < TC THEN L8 = .1
310  IF T > TC THEN L8 = 1:Z = 1
315 E1 = L8*E
320 R2 = JR / (1 + M6 * R * F * P + M2)
330 TR = 30 + Z * 1.2 * N9 * M
340 R = J / (1 + K0 * F * P * R2 + N4 * F * P * W)
350 L2 = LA + Z * LB
```

```
370 E2 = M1 * (K4 * M / P4)
380 IF T>155 GOTO 420
390  IF T < 133 THEN P4 = P4 +.001
400  IF T > 133 THEN P4 = .7
410  IF T > 143 THEN P4 = .3
420  IF T > 153 THEN P4 = .7
430 IF T>155 THEN P4 = P4 + .01
440  IF P4 > 4 THEN P4 = 4
450  REM    CHANGE EQUATIONS
460 DW = R2 - K2 * W - K3 * B * W * P * (E1 + E2) * (K5 * M / P5) - J1 * R * F *
 P * W
470 DF =  - K6 * F - K7 * R * F * P * R2 + M7 * A - J2 * R * F * P * W + M3 * R
* R2 * F * P
480 DB = K8 * R * F * P * R2 - K9 * B - L1 * B * W * (E1 + E2) * (K5 * M / P5) *
 P - M8 * B + J3 * R * F * P * W
490 DA = (L2 * B * W * (E1 + E2) * (K5 * M / P5) * P) + L7 * M / P3 - L3 * A - L
4 * A * P - M5 * A - Z * N1 * E * A
500 DM = (P1 * L5 * B * W * P * (E1 + E2) * (K5 * M / P5)) + L6 * G * V - P2 * L
6 * G * V + P2 * N8 * M - N8 * M - K4 * M - K5 * M - L7 * M - N9 * M + Z * P4 *
K1 * E * A + TR
510 DE =  - Z * M4 * B * W * P * (E1 + E2) * (K5 * M / P5) - Z * K1 * E * A
520 DG = N2 * B + N3 * A - N5 * G
530 DP = L9 * ((A / P) - FA) + N6 * P * A - N7 * P
540  REM  NEW VALUES OF STORAGES
550 M = M + DM * I
560  IF M < .0001 THEN M = .0001
570 A = A + DA * I
580  IF A < .01 THEN A = .01
590 W = W + DW * I
600  IF W < .0001 THEN W = .0001
610 B = B + DB * I
620  IF B < .00001 THEN B = .00001
630 P = P + DP * I
640  IF P < .1 THEN P = .1
650 G = G + DG * I
660 F = F + DF * I
670  IF F < .0001 THEN F = .0001
680 E = E + DE * I
690  IF E < 1 THEN E = 1
700 T = T + I
710  REM  GO BACK AND REPEAT FOR THE NEXT TIME INTERVAL
720  IF T / T0 < 320 GOTO 200
730  END
```

Appendix 17

Emergy Evaluation of Resource Basis for Mexico in 1983

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (E9 1983 US$)
1	Rain	7.97E18 J	8888/J	7.08	29.5
2	Tides	3 E17 J	23564/J	0.70	2.92
3	Waves	1.37E18 J	25889/J	3.54	14.7
4	Oil use	2.75E18 J	53000/J	14.57	60.7
5	Natural gas use	1.39E18 J	48000/J	6.67	27.8
6	Imports	23.1E9 $	2.9E12/$	6.70	27.9
7	Exports	19.3E9 $	2.4E12/$	4.63	19.3
8	Gross national product	1.21E11 $	2.9E12/$	35.09	146.2
9	Population	72E6 people	4.9E15/person	35.28	147.0
10	Hydroelectricity	2.4 E17 J	4 E4 sej/j	o.96	4.0

Sources:

Brown, A. "Mexico." Student report. International Energy Policy Research Project. Instructor M. Blissett, LBJ School of Public Affairs, The University of Texas. Unpublished manuscript. 1985.

Miller, M. "Energy Analysis of Mexico." Energy Analysis class report. University of Florida, Gainesville. Unpublished report. 1980.

Notes: Emergy flow in column 3 divided by 2.4 solar emjoules/$ for U.S. in 1983.

1. Rainfall: (0.81 m/y)(1.97 E12 m^2)(1E6 g/m^3)(5 J/g) = 7.97 E18 J/yr

2. Tides Miller (1980)

3. Waves Miller (1980)

4. Oil use production minus exports
((2.7 - 1.5) E6 bbl/day)(365 d/yr)(6.28 E9 J/bbl) = 2.75 E18 J/yr

5. Natural gas use: production minus export
(3750 E6 - 273 E6)(cu ft/d)(365 d/yr)(1.1E6 J/cu ft) = 1.39 E18 J/yr

6. Imports for 1981 (Brown, 1985)

7. Exports for 1981 (Brown, 1985)

8. 1982 GDP, $98.6 E9 + $23.1 E9 imports = 121.7 E9 $/yr

9. 72 E6 people (1985)

10. Electric power, coal equivalents
(239 E12 btu/yr)(1013 J/btu) = 2.4 E 17 J/yr

Appendix 18

Annual Rates of Emergy Flow across the Texas-Mexico Border

Note	Item	Mexico to Texas (E22 sej/y)	Texas to Mexico (E22 sej/y)
1	Fuels	8.8	-
2	Services in trade	4.6	6.7
3	Other $ exchanges	2.9	2.3
4	Immigrants	2.1	-
5	Drugs	0.5	-
6	Agricultural products	0.4	-
	Total	19.3	9.0
	Macrovalue, US 1983 E9 $/yr	80.4	37.5

Notes: To express in 1983 US $ divide by 2.4 E12 sej/$. To express in 1983 Mexican $ divide by 3.0 E12 sej/$.

1. Export of oil and gas from Mexico (table 4.6)
(273 E6 cu ft/day)(1.1E6 J/cu ft)(4.8 E4 sej/J)(365 d/y) = 0.53 E22
(250 E6 bbl/y)(6.3 E9 J/bbl)(5.3 E4 sej/J) = 8.3 E22
Refined:(42 T/day)(365 d/y)(1 E6 g/T)(3.7 E4 J/g)(6.3 E4 sej/J)=.0037
Oil and gas export: 8.8 E22 sej/y

2. Line 6 table 4.6; data for all imports exports to Mexico, of which the majority is with U.S.
Oil earnings(17.6 E9$/y)(3.0 E12 sej/$) = 5.8 E22 sej/y
Twin plants: ($1.4 E9/y)(2.4 E12 sej/$) = 0.34 E22 sej/y

3. 9.8 E9 $ interest payment Mexico to U.S.
(9.8 E9 $/yr)(3.0 E12 sej/$) = 2.94 E22

Earnings returned to Mexico assumed 10%
Income per person, $11,644;
(.10)($11,644/y)(2 E6 Mexican workers in U.S.) = $2.32 E9

4. Immigration based on 469,260 immigrants returned from Texas and immigration office statement that one of two pass without capture. If the average age is 25 yrs and the emergy supplied per person per year is 1.8 E15 sej/capita, then the emergy of storage in immigrants is:

(4.69 E5 people/y)(1.8 E15 sej/person/y)(25yrs)= 2.1 E22 sej/y

5. Data on drug traffic in 1983 assembled by Gregg Johnson (Narcotics Intelligence Estimate, 1983)

Item	Tons	$E9
Cocaine	50	4.38
Heroin	4	2.0
Marijuana	1360	37.6

Assume 1/4 through Texas
Assume 20% across border
(.25)(0.2)($44 E9) =$ 2.2 E9
($2.2E9)(2.4 E12 sej/$) = 0.53 E22

6. Agricultural imports to Texas $285 million/y
($285 E6/y)(1E6 g/ton)*(1.26 E4 J/g)(1 E5sej/J) /($100/ton) = 0.36 E22sej/y

Narcotics Intelligence Estimate 1983. National Narcotics Intelligence Consumers Committee, Drug Enforcement Administration, Washington, D.C.

Appendix 19

Emergy Analysis of a Water-pumping Farm Windmill

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E12 sej)	Macroeconomic value (1983 US $)
1	Wind availabe to vanes	1.17 E10 J	623	7.3	3.0
2	Services from cost	87 $	2.0 E12/$	174.	72.5
3	Steel equipment	1.49 E4 g	9.13 E8/g	13.6	5.67
4	Water lifting output	6.5 E8 J	2.35 E4/J	15.3	6.4
5	Chemical energy of water	8.5 E9 J	4.1 E4/J	350.	149.
6	Total input	--	--	560.2	236.6
7	Alternative, electricity				
	services	68 $	2.6 E12/J	177.	73.7
	electricity	2.45 E9 J	1.5 E5/J	367.	153.
	total			544.	226.7

Sources:

Bomar, G.W. Texas Weather. Austin, Texas: The University of Texas Press. 1983.

Essex Associates Catalog. 1986.

Notes: To calculate macroeconomic value, emergy flow in column 3 was divided by 2.2 solar emjoules/$ for U.S. in 1983. The windmill was an Essex Associates product (1986), 6 ft diameter on 21 ft tower, pumping water 180 ft as designed for 17 miles per hour wind.

1. Wind energy available at rated capacity, 17 miles per hour (Bomar, 1983)
   (17 mi/hr)(1584 m/mi)/(3600 s/hr) = 7.5 m/s

   6 foot(1.8 m) cross section; area =(3.140(0.9m)(0.9 m) = 2.54 m^2

   Energy per air volume: (.5)(1.23 kg/m^3)(7.5m/s)(7.5m/s) = 334.6 J/m^3

   (34.6 J/m^3)(4.22 m/s)(2.54 m^2)(3.154 E7 sec/y) = 1.17 E10 J/y

2. Equipment costs in 1985 $: Windmill head, $841; 21 ft tower, $898
   ($1739)/(20 yr life) = $87

3. Steel: head, 206 lb; 21 ft tower 450 lbs
   (656 lb)(454 g/lb)/(20 year life) = 1.49 E4 g/y

4. Energy in water pumped, 17 mph, 12 hrs, 105 gallons per hour from 130 ft:

(105 gal/hr)(3.7 kg/gal)(9.8 m/sec^2)(130 ft)(0.3 m/ft)(12 hr/day)(365 d/y) =
= 6.5 E8 J/y

Water pumped: (105 gal/hr)(12 hr/day)(365 d/y) = 4.6 E5 gal/y
(4.6 E5 gal/y)(3.7 E-3 m^3/gal) = 1702 m^3/y

5. (105 gal/hr)(3.7 E3 g/gal)(5 J/g)(12 hr)(365 d/y) = 8.5 E9 J/y

6. Total of solar emergy inputs from environment and economy (items 1-5)

7. Alternative from rural electric power at $.15/1000 gallons
($.15/1000 gal)/(3.7 m^3/1000 gal) = $.04/m^3 water

(1702 m^3/yr)($.04/m^3) = 68 $/y

Electricity ($ 68/y)/($.10/kilowatt-hour) = 680 kwh/y
(680 kwh/y)(3.6 E6 J/kwh) = 2.45 E9 J/y

Appendix 20

Emergy of Inputs to the Texas Coastal Zone

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E21 sej/yr)	Macroeconomic value (1980 US E9$/y)
1	Sunlight	0.72 E21j	1	0.72	0.33
2	Rainfall				
	Land, bays	2.8 E17j	1.54 E4	4.33	1.92
	Shelf	2.5 E17j	1.54 E4	3.84	1.75
3	River waters	1.86 E17J	41068	7.64	3.47
	Organic matter	1.87 E16j	1.9 E4	0.36	0.15
	Phosphorus	3.73 E10g	1.4E10/g	0.52	0.24
	Sediments	3.73 E12g	1.71 E9/g	6.4	2.7
4	Waves on beach	2.3 E17j	25889	5.95	2.7
5	Tides, wind set	4.4 E16	23564	1.04	0.47
6	Oil production	1.8 E18J	5.3 E4	96.1	43.7
7	Gas production	3.74 E18J	4.8 E4	180.	81.6
8	Oil & gas prod.	-	-	276.1	125.3
9	Oil & gas use	-	-	116.	52.7
10	Oil & gas sold outside	-	-	160.1	72.6
11	Commercial fish	5.43 E13	8 E6/J	0.43	0.179
	Comm fish service	188. E6$	2.4 E12/$	0.45	0.19
12	Oysters	0.99 E13	3 E6/J	0.03	0.013
	Oyster services	8.3 E6$	2.4 E12/$	0.02	0.008
13	Sports fish serv	8.88 E8$	2.2 E12/$	2.13	0.88
14	Crabs	8.23 E12 J	5.95 E6 J	0.05	0.02
15	Imported goods and services	5.9 E9$	2.2 E12/$	13.0	5.9

Sources:

Bahr, L.M., J. Day, and J.H. Stone. "Energy cost-accounting of Louisiana fishery production." Estuaries Vol. 5, 1982, pp. 209-215.

Brown, M.T. Energy Basis for Hierarchies in Urban and Regional Landscapes. Ph.D. diss. Dept. of Environmental Engineering Sciences, University of Florida, Gainesville, Fl., 1980, pp. 359.

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Dallas Morning News. Texas Almanac, 1984-1985. 1983.

Odum, H.T., M. Kemp, M. Sell, W. Boynton, and M. Lehman. "Energy Analysis and Coupling of Man and Estuaries." Environmental Management, 1,297-315. 1977.

Odum, H.T. and C. Diamond. Energy systems overview of the Mississippi River Basin. Center for Wetlands, Technical Report, University of Florida, Gainesville, Fl. 1987. (draft)

Odum, H.T. and E.C. Odum. Energy Analysis Overview of Nations. Working Paper WP-83-82. International Institute for Applied Systems Analysis, Laxenburg, Austria. 1983.

Plaut, J.E., R.J. Wright, and M.C. Anderson. Texas Fact Book 1984. Bureau of Business Research, The University of Texas at Austin, Texas. 1983.

Texas Parks and Wildlife, Dept. of Coastal Fisheries, phone call.

Visher, S.S. Climatic Atlas of the United States. Cambridge, Mass.: Harvard University Press. 1954.

Notes: To calculate macroeconomic value, emergy flow in column 3 was divided by 2.2 solar emjoules/$ for U.S. in 1980. Part of the data were assembled by Marilyn Hunt.

Areas: counties, 21,000 square miles
(2.1E4 sq mi)(640 acres/sq mi)(4.05 E3 m^2/acre) = 5.44 E10 m^2
Bays: Galveston, Matagorda, San Antonio, Copano, Corpus Christi. and Laguna Madre: (1.486 E6 acres)(4.05 E3 m^2/acre) = 6.02 E9 m^2
Continental shelf: (88.5 km)(5.87 E5 m)(1000 m/km) = 5.02 E10 m2

1. Sunlight: Solar Transformity = 1 by definition. Total insolation, 4250. kcal/m^2/day (Visher, 1954); 4186 J/kcal; 365 days/y.

(6.49 E9 J/m^2/yr)(11.06 m^2 including shelf) = 7.17 E10 J/yr

2. Rainfall:Mean of 23 counties (Texas Almanac, 1984-85):
(39.29 inches)(25.4 mm/inch) = 998 mm/y
Area of land and bays:
(998 mm/y)(5.64 E10 m^2)(1E3 g/mm/m^2)(5 J Gibbs free energy/g) = 2.8 E17 J/ha/y;
Transformity from world hydrology web (Odum and Odum, 1983)
Shelf area:
(998 mm/y)(5.0 E10 m^2)(1E3 g/mm/m^2)(5 J Gibbs free energy/g) = 2.50 E17 j/y

3. Rivers: sum of 11 (Brazos, Colorado, Guadalupe, Lavaca, Neches, Nueces, Sabine, San Antonio, San Jacinto, and Trinity):

(30.17 E6 acre-ft/y)(4.05 E3 m^2/acre)(.305 m/ft) = 3.73 E10 m^3/y
(3.73 E10 m^3/y)(1E6 g/m^3)(5 J/g) = 1.86 E17 J/y

Phosphorus concentrations: in rivers, 1 g/m^3; in bays, 0.3 g/m; on shelf, .011 g/m^3.

(3.73 E10 m^3/yr)(1 g/m^3 P) = 3.73 E 10 g P/y

Organic matter contributions: 30 g/m^3 organic matter in rivers.
(3.73 E10 m^3/yr)(30 g/m^3)(4 kcal/g)(4186 J/kcal) = 1.87 E16 J/y

Transformity from footnote 12.

Suspended sediments: order of magnitude 100 g/m^3
(3.73 E10 m^3/y)(100 g/m^3) = 3.73 E12 g/y

4. Waves: shoreline, 5.87 E5 m; 1 m wave height measured at 8 m depth

(1/8)(5.87E3m)(1.025 kg/m^3)(9.8 m/sec^2)(1 m)(square root of (9.8 m/sec^2 * 8 m) (3.154 E7 sec/y) = 2.5 E17 J/y = 2.3 E17 J/y

5. Sea level changes releasing energy over the shelf area due to tide and wind set. Area, 5 E10 m^2; height, 0.5 m

(0.5)(5E10 m^2)(0.5 m)(1.025E3 kg/m^3)(9.8 m/sec^2)(706/y) = 4.4E16 J

6. Oil production in 19 coastal counties, 289 E6 barrels.

(289 E6 bbl/y)(6.28 E9 J/bbl) = 1.8 E18 J/y

7. Natural gas production: ratio of gas to crude oil in a Gulf Coast area (counties somewhat different from those of this table): 1490 E9 cu.ft. to 125 E9 bbl (Bullock, 1984), which is a ratio of 2.08 on a joule basis.
(2.08 gas/crude oil)(1.8 E18 J/y crude oil) = 3.74 E18 J/y

8. Oil and gas production: sum of notes 6 and 7.

9. Oil and gas use as population percentage of state use.

(0.28)(24.43 E22 + 17.03 E22 sej/y) = 116. E21 sej/y

10. Oil and gas export from region: difference between notes 8 and 9.

11. 1983 services involved in fisheries catch in bays, \$3.75E6 and in Gulf, \$184 E6; Weight of commercial fish: 28.3 E6 lbs/yr; source: TNLS, Inc. per Texas Parks and Wildlife Dept. Coastal Fisheries.

(28.3 E6 lbs/y fresh)(454 g/lb)(0.2 dry of fresh)(5 kcal/g)(4186 J/kcal) = 5.43 E13 J/y

12. Oysters 5.2 E6 lbs; \$8.3 E6 (Texas Parks and Wildlife Dept., Coastal Fisheries)
(5.2 E6 lbs/y)(454 g/lb)(0.1 dry/freshs)(5 kcal/g)(4186) =9.9E12 J/y

Transformity of fisheries food chain items derived by Odum and Diamond (1986) from food chain data from Bahr, Day, and Stone (1982) :

gross production	4,687 sej/J
dispersed algae	9,374 sej/J
dispersed organic matter	18,749 sej/J
zooplankton & microzoa	140,610 sej/J
dispersed herbivores	1,406,100 sej/J
upper consumers	7,967,900 sej/J

13. Services to sports fisheries: \$8.88 E8 (Texas Parks and Wildlife)

14. Commercial crabs, annual catch 7.2 E6 lb; \$2.2 E6
(7.2 E6 lb)(454 g/lb)(0.2 dry/fresh)(1.26 E4 J/g) = 8.23 E12 J/yr
At Crystal River, Fl. 5.62 g/m^2 day organic matter generates 4.43 milligrams/m^2 blue crabs (M. Kemp and M. Homer);
organic production transformity, 4,687 sej/j footnote 12;
Crab transformity:
(4,687 sej/gross prod)(5.62/4.43 E-3)= 5.95 E6 sej/j

15. Goods and services entering area estimated from nomogram relating exchange to economic density per area (Brown, 1980):

Population of 23 counties in 1980, 4.3 million; which is 4.3/15.3 million of 28% of the people in Texas. Gross state product for Texas is 230 E9 \$/year (<u>Texas Fact Book</u>, p. 118); Prorating state product in proportion to people: (0.28)(230 E9 1981 \$) = 64.4 E9 \$/y

Areal economic density: (64.4 E9 \$/y) / (5.44 E10 m^2) = 1.18 \$/m^2/y
(1.18 \$/m^2/y)(2.59 E6 m^2/square mile) = 3.06 E6 \$/square mile

On the nomogram this density indicates 0.28 E6 \$/square mile exchange:
(0.28 E6 \$/sq mi)(5.44 E10 m^2) / (2.59 E6 m^2/sq mi)) = 5.9 E9 \$/y

Appendix 21

Emergy Analysis of Marshes Receiving Treated Wastewaters
at Port Aransas Texas

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E15 sej/y)	Macroeconomic value (1985 US $)
1	Sun	2.6E15 J	1/J	2.63	1,315.
2	Rain	1.47E12 J	1.54E4/J	22.6	11,300.
3	Waste water	5.96E12 J	4.1E4/J	244.	121,975.
4	Tidal energy	5.95E12 J	23564/J	140.	76,000.
5	Phosphorus	3.57E6 g	1.4E10/g	50.0	25,019.
6	Total organic	4.48E11 J	3E4/J	13.4	6,700.
7	Services and equipment	1.36 E6 $	2.0 E12/$	2732.	1,366,000

Sources:

Johnson, Gregory S. "A Wetland Ecosystem for Municipal Tertiary Treatment at Port Aransas, Texas." Unpublished student report for Policy Research Project course, The University of Texas at Austin, LBJ School of Public Affairs. pp. 114-118.

Nueces County. Water Control and Improvement District No. 4, 1984. Plant operator reports. Walter Revell, Operator. 1985.

Notes: To calculate macroeconomic value, emergy flow in column 5 was divided by 2.0 E12 solar emjoules/$ for U.S. in 1985.

1. Insolation: (1.59 E6 kcal/m^2/y)(4186 J/kcal) = 6.69 E9 J/m^2/y
   Area of marsh: (100 acres)(4.05 E3 m^2/acre) = 4.05 E5 m^2
   (6.69 E9 J/m^2/y)(4.05 E5 m^2) = 2.69 E15 J/y

2. Rain: (4.05 E5 m^2)(28.53 in/y)(0.0254 m/in)(1 E6 g/m^3)(5 J/g) = 1.47 E12

3. Wastewater (Nueces Co., 1984, 1985): (322 E6 gal/y)(3.7 liter/gal)(1 E3 m^3/liter)(1 g/cm^3) = 1.19 E12 g/y
   (5 J/g Gibbs)(1.19 E12 g/y) = 5.95 E12 J/y

4. Tidal energy: (0.5)(0.5 m)(.5 m)(4.05 E5 m^2)(706/y)(1.025 E3 kg/m^3)(9.8 m/sec^2) = 3.59 E11 J/y

5. Phosphorus: assume 3 mg/liter
   (3 mg/l)(322 E6 gal/g)(3.71/gal)(1000 mg/g = 3.57 E6 g of phosphorus/y

6. Total organic: (20 mg/l)(322 E6 gal/g)(3.71/gal)/(1 E10 mg/g) = 2.38 E7 g/y
   (2.38 E7 g/y)(4.5 kcal/g)(4186 J/kcal) = 4.48 E11 J/y

7. Budget for water transport and sewer for Port Aransas for 1986-87, $1.36 E9/y
   ($1.366 E6/y)(2.0 E12 sej/$) = 2732 E15 sej/y

Appendix 22

Emergy Analysis of Water in Figure 5.1

Note	Item	Water m^3	Raw Units	Transformity (sej/unit)	Solar Emergy (E12 sej/y)	Macroeconomic value (1985 US $)
Value of 1 cubic meter of agricultural water						
1	Rain water	71.4	3.6E8 J	15444/J	5.5	2.50
2	Rivers, lakes	7.1	3.4E7 J	41068/J	1.41	0.64
3	Ground water	1.	4.9E6 J	110314/J	0.54	0.25
4	Electricity for pumping	1.	2.0E6 J	1.59E5/J	0.32	0.15
5	Pipes, concrete	1.				
6	Goods, services	1.	0.04 $	2.2E12/J	0.088	0.04
7	Agricultural water	1.		255,242/J		0.44
8	SUMMARY: Price of agricultural water is $50/acre-ft. = $.15/ 1000 gallons. Macroeconomic value to the economy is $543/acre-ft. = $1.67/ 1000 gallons.					
Value of 1 cubic meter of residential water						
3	Groundwater (see above)					0.25
9	Electricity	1.	1.71E6 J	1.59E5/J	0.273	0.12
10	Pipes,concrete	1.				
11	Goods,services	1.	0.79 $	2.2E12/$	1.74	0.79
12	Consumer water	1.		665,714/J		1.16
13	SUMMARY: Price of residential water is $3.00 per 1,000 gallons. Macroeconomic value to the economy ia $4.39 per 1,000 gallons.					

Note: To calculate macroeconomic value, emergy flow in column 3 was divided by 2.2 E12 solar emjoules/$ for U.S. in 1985. Agricultural figures are for Texas plains; urban uses are for Austin.

Footnotes for 1 m^3 of agricultural water

1. 1.4% of rain water reaches ground water. So, for 1 m^3 of ground water:

   1.3/.014 = 71.4 m3

$1m^3$ water weighs 1E6g; rain water is 5J/g; emergy/$ ratio for 1985: 2.2E12SEJ/$

   (1E6g)(5J/g) = 5E6 J
   (5E6J)(71.4m^3) = 3.57E8 J

2. 10% reaches rivers and lakes = 7.14m^3; river water is 4.9J/g

   (1E6g)(4.9J/g) = 4.9E5 J
   (4.9E5J)(7.1m^3) = 3.4E7 J

3. Ground water is 4.9J/g

   (4.9J/g)(1E6g)(1m^3) = 4.9E6 J

4. Data from R.J. King, Dept. of Texas Agriculture: 680 KWH/acre-foot for 350 ft depth.

   (680KWH/acre-ft)(3.6E6J/KWH)/(1233m^3/acre-ft) = 2.0E6 J/m^3 water pumped 350 ft.

5. Value of pipes and concrete ?

6. Price of pumped water is $50/acre-foot; 1 acre-ft = 1233m^3

   $50/acre-ft/1233$m^3$/acre-ft = $.04/$m^3$

7. Total of ground water, electricity, and goods and services.

   0.25 + 0.15 + 0.04 = 0.44

Transformity of agriculture irrigation water pumped from the aquifer:

   ((1.10E5sej/J)(4.9E6J)+(8.8E10sej)+(3.2E11))/(1m^3)(1E6gl/m^3)(4.9J/g) = 255,242 sej/J

8. ($.44/$m^3$)(/(1233$m^3$/acre-ft) = $542.52/acre-ft

Summary: The price of 1 acre-foot of agricultural water is $50 / acre-foot. The macroeconomic value to the economy is $543 / acre-foot.

Footnotes for 1m^3 of residential water

9. Yearly electrical use for water pumping in Austin in 1984/85: 57,754,186 KWH for 32,235,000,000 gallons (pumping, treatment, and distribution).

$$(57.7E6KWH)(3.6J/KWH) = 2.08E14J$$
$$(32E9gal)(3.785E\text{-}3m^3/gal) = 1.21E8m^3$$
$$2.08E14J/1.21E8m^3 = 1.71E6J/m^3$$

10. Value of pipes and concrete -?

11. Price of residential water is \$3/1,000 gal; 1 gal = $3.785E\text{-}3m^3$

$$(\$.003/gal)/(3.785E\text{-}3) = \$.79/m^3$$

12. Total of ground water, electricity, and goods & services (3+4+5+6)

$$0.25+0.12+0.79 = 1.16$$

Transformity of consumer water

$$((4.9E6J)(2.55E5sej/J)+(2.73E11)+(17.4E11))/4.9E6J = 6.66E5\ sej/J$$

13. $(\$1.16/m^3)/(264.2gal/m^3)(1,000) = \$4.39\ /\ 1,000$ gallons

Summary: The price of residential water is \$3.00 per 1,000 gallons. The macroeconomic value to the economy is \$4.39 per 1,000 gallons.

Appendix 23

Emergy Analysis of Lignite Mining and Electric Power Plant
Rates per Day

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E17 sej/d)	Macroeconomic value (1983 US$/d)
MINING SYSTEM					
1	Land production diverted	7.10 E11J	1.5 E4/J	0.011	484
2	Topsoil lost	5.04 E12J	6.3 E4/J	3.1	140,909
3	Fuel used by vehicles	6.38 E10J	5 E4/J	0.032	1,449
4	Electricity used	3.11 E11J	1.6 E5/J	0.49	22,272
5	Equipment maintenance	13.8 tonne	6.7 E15/t	0.93	42,272
6	Goods and services costs	2.8 E5 $	2.2 E12/4	6.2	281,818
7	Lignite to power plant	2.0 E14J	3.68 E4/J	73.7	3,350,090
POWER PLANT					
8	Water used in cooling	2.43 E11J	4.1 E4/J	0.10	4,545
9	Equipment maintenance	18.5 tonne/d	6.7 E15/t	1.24	56,341
10	Goods and services costs	1.82 E6 $	2.2 E12/$	40.	1,818,181
11	Electric production	7.27 E13 J	1.6 E5/J	116.	5,272,727

Notes: To calculate macroeconomic value, emergy flow in column 3 was divided by 2.2 solar emjoules/$ for U.S. in 1983.

1. Land used per day estimated from tons mined
   (1 ton)(908,000 g/ton)/((2.4 m seam)(1.5E 6 g/m^3)) = 0.25 m^2/ton

   (0.25 m^2/ton)(20,000 ton/d) = 5000 m^2/d

   (5000 m^2/d)(3 years out of use)(365 d/y) = 5.47 E6 m^2 out of use

   (5.47 E6 m^2)(1 E6 g transpiration/m^2/yr)(5 J/g)/(365 d/y) = 7.49 E10 J/d

2. Topsoil lost
(5000 m^2/d)(1 m deep)(1.47 E6 g/m^3)(.03 organic)(2.26 E4 J/g) = 5.04 E12 J/d

3. Diesel fuel used, 175,000 gallons/yr
(175,000 gal/yr)(3.5 E3 g/gal)(3.8 E4 J/g)/(365 d/yr) = 6.38 E10 J/yr

4. Electricity used
(4.5E3 kilowatts)(0.8 capacity)(24 hr/day)(3.6 E6 J/kwh) = 3.11 E11 J/day

5. Equipment maintenance-replacement steel equivalence of 17% of cost
(.17)($280,000/d)/($3447/tonne steel products) = 13.8 tonne/yr

6. Goods and Services cost
(20,000 tons/day)($14/ton) = $280,000/day

7. Lignite transported to plant
(20,000 tons/day)(1.0 E10 J/ton) = 2 E14 J/day
Transformity estimated from Electric emergy minus goods-service emergy
(115 - 41.3 E17 sej/day) / (2.0 E14 J/day) = 3.68 E4 sej/J

8. Water in cooling
(2400 acre)(4.04 E3 m^2/acre)(5000 g/m^2/day evap,)(5 j/g) = 2.43 E11 J/day

9. Equipment maintenance-replacement
plant cost in current $
(0.7 E9$/30 yr)/($3447/tonne)(365 d/yr) = 18.5 tonne/day

10. Goods and Service costs
(2.0 E7 kwh/d)($.09/kwh) = 1.82 E6 $/day

11. Electric production
(0.8)(1050 E3 kw)(24 hr/day)(3.60 E6 J/kwh) = 7.23 E13 J/day

Appendix 24

Emergy Analysis of Inputs to Texas Highway Construction and Use

Note	Item Type of Energy	Actual Energy (unit/y)	Transformity (sej/unit)	Solar Emergy (E22 sej/y)	Macro $ (E9 $/y)
1	Earth cycle	1.02 E18	2.9 E4	2.96	13.45
2	Earth cycle	4.2 E15	2.9 E4	0.01	0.045
3	Earth loss	1.23 E14	2.9 E4	0.00036	0.0016
4	Motor vehicle	2.5 E7	6.7 E15	16.75	76.14
5	Asphalt	9.07 E16	3.47 E5	3.15	14.32
6	Cement	2.42 E11	3.3 E10	0.792	3.59
7	Steel	2.69 E4	1.78 E15	0.0048	0.022
8	Total budget	1.97 E9	2.2 E12	0.43	1.95
9	Federal funds	8.5 E8	2.2 E12	0.19	0.86
10	Budget for maintenance	4.24 E8	2.2 E12	0.093	0.42
11	Budget for construction	1.36 E9	2.2 E12	0.29	1.32
12	Litter cost	1.7 E7	2.2 E12	0.0037	0.017
13	Labor services	4.85 E15	8.1 E4	0.039	0.177
14	Fuel consumption	1.41 E18	6.6 E4	9.31	42.32
15	Electricity	3.27 E15	15.9 E4	0.052	0.24
16	Driver	5.31 E16	8.1 E4	0.43	1.95

Sources:

Ethyl Corporation, Energy Information Administration, and Asphalt Institute, Data compiled by IPAA, Sept. 1984.

Lyu, Wernhuar. "Emergy Analysis of Highway Transportation in Texas." Unpublished student report for Policy Research Project course, The University of Texas at Austin, LBJ School of Public Affairs. pp. 130-157. 1986.

Statistical Abstract of the U.S. Washington, D.C. 1985.

Texas Department of Highways and Public Transportation. Annual report. Austin, Texas. 1984, 1985.

Texas Department of Highways and Public Transportation. Bob Jackson, Policy Development Division, personal communication. 1987.

Texas Employment Commission, Economic Research and Analysis Department.

U.S. Department of Energy, Energy Information Administration 1985. State Energy Overview, Washington, D.C. 1985.

Notes:

1. Earth cycle. Texas surface area assigned heat flows based on ages, and the following method:
(land area of Texas)(heat flow per area)
Land area of Texas: 7 E11 m^2 (Statistical Abstract of the U.S. 1985)
(7 E11 m^2)(1.45 E6 $J/m^2/y$)(= 1.02 E18 J/y

2. Earth cycle. (land area of Texas highway)(heat flow per area)
Total land area of Texas highways: 7.15 E5 acres (Report of State Dept. of Highways and Public Transportation. Jan. 31. 1984.)
1 $mile^2$=640 acres=2.59 E6 m^2 (7.15 E5)(2.59 E6)/(640) = 2.90 E9 m^2
(2.90 E9 m^2)(1.45 E6 $J/m^2/y$) = 4.2 E15 J/y

3. Earth loss. ((erosion rate)-(formation))(land area of Texas highway)
((93.6 $g/m^2/y$)-(31.2 $g/m^2/y$))(2.90 E9 m^2) = 1.81 E11 g/y
(1.81 E11 g/y)(0.03 organic)(5.4 kcal/g)(4186 J/kcal) = 1.23 E14 J/y

4. Motor vehicle. Total weight of registered motor vehicles in 1983: 2.5 E7 tons (Raw data from Highway Dept., aggregated by Wernhuar Lyu.)
(2.5 E7 tons)(6.7 E15 sej/t)=16.75 E22 sej - storage
Depreciation rate estimated: 10%

5. Asphalt. 5.5 bbls = 1 sh. ton
Total asphalt consumed in 1983: 14.45 E6 bbls/y (Sources: Ethyl Corporation. Energy Information Administration and The Asphalt Institute. Data compiled by IPAA, September 1984).
(14.45 E6 bbls/y)(6.28 E9 J/bbl) = 9.07 E16 J/y
The transformity of asphalt is 3.47 E5 sej/J
Method for evaluating the transformity of asphalt:
(Energy for producing petroleum products)/(amount of petroleum product produced) = transformity of this petroleum product
(crude petroleum)--->(refining)--->fuels---88.4%
These fuel products include (1) gasoline 48.2%. (2) distillate fuel 18.7%. (3) residual fuel 6.5%. (4) jet fuel 7.8%. (5) petrochemical feedstocks 3.2%. and (6) still gas for fuel 4.0%.
--->asphalt------------2.8%
--->coke and others----8.8%
The above petroleum product proportion is according to the Statistical Abstract of the United States 1985, p. 705, table 1253. We use an average of the six fuel proportions to estimate the transformity of asphalt. This should avoid overestimating the transformity of asphalt. Thus, the average proportion of fuels would be equal to

(88.4)/(6) = 14.73

Figure 8.4 is a flow chart of producing the petroleum asphalt.
The proportion of asphalt to fuel is 2.8:14.73 = 1:5.26
It means that we use the same energy to produce one unit of asphalt and 5.26 units of fuels. As a result, the transformity of asphalt is 5.26 times larger than that of fuels. Because the transformity of fuels is 6.6 E4 sej/J so we can find the transformity of asphalt by the following method: (5.26)(6.6 E4 sej/J) = 3.47 E5 sej/J
(9.07 E16 J/y)(3.47 E5 sej/J) = 3.15 E22 sej/y

6. Cement. Total cement consumed: 2.67 E5 tons/y (Raw data from Texas Highways Dept., aggregated by Wernhuar Lyu.)
1 ton = 907.19 kgs
(2.67 E5 tons/y)(907.19 kg/t) = 2.42 E8 kg/y = 2.42 E11 g/y
(2.42 E11 g/y)(3.3 E10 sej/g) = 7.92 E21 sej/y = 0.792 E22 sej/y

7. Steel. Total steel used: 2.69 E4 tons/y (Raw data from Texas Highways Dept., aggregated by Wernhuar Lyu.)
(2.69 E4 tons/y)(1.78 E15 sej/t) = 0.0048 E22 sej/y

8. Total Budget: 1.97 E9 $/y (Report of Texas Highways Dept., fiscal year ending on Aug. 31, 1984.)
Budgets for Texas highway included federal grants and state budgets
(1.97 E9 $/y)(2.2 E12 sej/$) = 0.43 E22 sej/y

9. Federal Funds: 8.5 E8 $/y (Report of Texas Highways Dept., fiscal year ending on Aug. 31, 1984.)
Budgets for Texas highway which is federal funds.
(8.5 E8 $/y)(2.2 E12 sej/$) = 0.19 E22 sej/y

10. Budget for maintenance 4.24 E8 $/y (Report of Texas Highways Dept., fiscal year ending on Aug. 31, 1984.)
(4.24 E8 $/g)(2.2 E12 sej/$) = 0.093 E22 sej/y

11. Budget for construction: 1.36 E9 $/y (Report of Texas Highways Dept., fiscal year ending on Aug. 31, 1984.)
(1.36 E9 $/y)(2.2 E12 sej/$) = 0.29 E22 sej/y

12. Litter cost: 1.7 E7 $/y (Report of Texas Highways Dept., fiscal year ending on Aug. 31, 1984.)
Expenditure for cleaning Texas highway litter.
(1.7 E7 $/y)(2.2 E 12 sej/$) = 0.0037 sej/y

13. Labor service. Embodied energy per person per year:
(2500 kcal/person/day)(4186 J/kcal)(365 d/y) = 3.82 E9 J/person/y
Total labor service for Texas highway: 1.27 E6 person/y (Sources: Texas Employment Commission, Economic Research and Analysis Dept. Trans. Equipment 97.4 E3 trans. and public utilities 366.2 E3 trans. exc. railroads 170.6 E3 electric services 44 E3, automotive dealers 129.5 E3, construction 424 E3, petroleum refining 40.7 E3. The last two are evaluated for highways const. and maint.)
Services for highways construction and maintenance: 4.65 E5 person/y
(1.27 E6 person/y)(3.82 E9 J/person/y) = 4.85 E15 J/y
(4.85 E15 J/y)(8.1 E4 sej/J) = 0.039 E22 sej/y = total services
(4.65 E5 person/y)(3.82 E9 J/person/y) = 1.78 E15 J/y
(1.78 E15 J/y)(8.1 E4 sej/J) = 0.014 E22 sej/y for const. and maint.

14. Fuel consumption. Vehicle miles of Texas highway travel: 1.32 E11 miles/y in 1983
(State Energy Overview, Aug. 1985, Energy Information Administration, U.S. Dept. of Energy.)
Average mileage per gallon: 14.05 miles/gallon
(Statistical Abstract of the U.S., 1985, p. 601, table no. 1047)
Total fuel consumption: 2.25 E8 bbls/y (1983)
(Ethyl corporation, Energy Information Administration, and The Asphalt Institute, compiled by IPAA, Sep. 1984.)
(2.25 E8 bbls/y)(6.28 J/bbl) = 1.41 E18 J/y
(1.41 E18 J/y)(6.6 E4 sej/J) = 9.31 E22 sej/y = total fuel consumption
Total lane miles constructed in 1983: 1423 lane miles
(Data from Bob Jackson, Policy Development Division, Highways Dept.)
Total lane miles maintained in 1983: (177,039-1423) = 175,616
Fuel consumption of maintenance:
(175,616 lane miles)(4)/(14.05 miles/gallon) = 5.00 E4 gallons
Fuel consumption of construction:
(1423 lane miles)(1000)(14.05 miles/gallon) = 1.01 E5 gallon
Note: The above numbers for fuel consumption of highways construction and maintenance are only estimates.
Fuel consumption of highways construction and maintenance:
((1.01 E5+5.00 E4) gallons/y)/(31.5 gallons/bbl) = 4.79 E3 bbls/y
(4.79 E3 bbls/y)(6.28 E9 J/bbl) = 30.08 E12 J/y
(30.08 E12 J/y)(6.6 E4 sej/J) = 198.5 E16 sej/y = 0.0002 E22 sej/y
Construction and maintenance = 0.0002 E22 sej/y

15. Electricity and consumption. Street and highway light electricity consumption in 1983: 907 E6 KWH (Data from the Public Utility Commission.)
(power units for a time)(energy per unit power for a time)
(907 E6 KWH/y)(3.60 E6 J/KWH) = 3.27 E15 J/y
(3.27 E15 J/y)(15.9 E4 sej/J) = 51.99 E19 = 0.052 E22 sej/y

16. Drivers. Each motor vehicle is supposed to have one operator (driver).
Total number of drivers = total number of registered motor vehicles
= 1.39 E7
(Number of registered motor vehicles is given by the Highway Dept.)
In reality, there may be some drivers who own more than one motor vehicle and some others who do not have any motor vehicle.)
Embodied energy per person per year:
(2500 kcal/person/day)(4186 J/kcal)(365 d/y) = 3.82 E9 J/person/y
Total energy yielded from drivers:
(1.39 E7 persons/y)(3.82 E9 J/person/y) = 5.31 E16 J/y
(5.31 E16 J/y)(8.1 E4 sej/J) = 0.43 E22 sej/y

Appendix 25

Annual Macroeconomic Values with Option I, Landfill
(figure 6.4b)

Note	Item	Million $/yr
1	Municipal solid waste components	- 26,690.
2	Land productivity diverted	- 47.
3	Land cost	- 43.
4	Heavy metal leakage to groundwater	- 56.
	Sum of items 1-4	- 26,755.

Source:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Notes: 1983 J.S. $; annual emergy flow was divided by 1983 emergy/$ ratio for U.S., 2.4 E12 sej/$. Loss of resources from potential use is given a minus.

1. Sum of items 1-12 from appendix 30

2. Item 13, appendix 30

3. Item 14, appendix 30

4. Using copper (Cu); estimated by proportion. Copper concentration in dump (0.2%) is 67 times higher than typical soil (0.003 %, Bowen, 1979). Leakage estimated as 67 times normal copper leakage from soil (0.7 milligrams/m^2/y) with 10 times the depth of deposit

(10)(67)(0.0007 g/m^2/y)(1800 ac/y)(40 y)(4.05 E3 m^3/ac) = 1.37 E9 g/y

(1.37 E9 g/y)(9.9E10 sej/g)/(2.4 E12 sej/$) = 1.36 E20 sej/y

Appendix 26

Annual Macroeconomic Values with Option II, Reuse and Landfill
(figure 6.4d)

Note	Item	Million $/yr
1	Sum of emergy of recyclables	8,890.
2	Copper and zinc alloys	670.
3	Toxic drainage prevented	56.
4	Separation and recycling costs	- 1,904.
5	Reuse contribution	+ 7,712.
6	Land productivity diverted + land cost	- 35.
7	Macrovalue of landfilled components lost from use	- 16,906.
	Landfill waste, sum of item 6 and 7	- 16,941.
	Net Contribution	- 9,229

Source:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Notes: 1983 U.S. $; annual emergy flow was divided by 1983 emergy/$ ratio for U.S., 2.4 E12 sej/$.

1. Sum of items 2,8,9,11 from table 15.1) = 8.81 E9 $/y

2. Item 10 from appendix 30

3. Item 4 in appendix 25

4. Sum of items 18-22 on appendix 30) = 1.904 E9 $/y

5. (sum of items 1 and 2 minus item 3)

6. Values lost in Landfill, 39% of that without reuse:
   39% of items 13 and 14 in appendix 30
   (0.39)(47 + 43 E6$) = 35.1 E6 $/y

7. Sum of items 1,3,4,5,6,7,12 in appendix 30

Appendix 27

Annual Macroeconomic Values with Option III, Incineration and Fill (figure 6.4c)

Note	Item	Million $/yr
1	Electricity	97.9
2	Incinerator cost	- 202
3	Land productivity diverted and land cost	- 26
4	Toxic leaching	- 1,400
5	Ash buried	- 8,592
	Net Loss	- 10,122

Source:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Notes: 1983 U.S. $; annual emergy flow was divided by 1983 emergy/$ ratio for U.S., 2.4 E12 sej/$.

Fill includes 10% of combustibles (items 1-7 in appendix 30) plus noncombustibles totalling 3.783 E6 tons of "ash"; This is 29% of original 13 E6 tons.

1. 2.35 E20 sej/y

2. Item 4 in appendix 26

3. 29% of items 2 and 3 in appendix 25 = 26.1 E6 $/y

4. Item 3 in appendix 26 accentuated by concentration factor: 100/4 = 25 times

5. 29% of total ash (13 E6 tons) = 0.52 E6 Tons
   emergy of solid waste, sum of items 1-12 from appendix 30 = 6.4 E22 sej/y

   Transformity of ash:
   (6.4 E22 sej/y)/(13 E6 Ton * 0.9E6 g/Ton) = 5.47 E9 sej/g
   29% of ash: (3.77 E12 g)(5.47 E9 sej/g)/(2.4 E12 sej/$) = 8492 E6 $

Appendix 28

Annual Macroeconomic Values with Option IV,
Reuse, Incineration, and Fill
(figure 6.4e)

Note	Item	Million $/y
1	Recyclables including copper and zinc	9,560
2	Electricity yielded	38
3	Reuse contribution	9,598
4	Separation and reuse costs	-1,904
5	Incinerator cost	- 192
6	Land productivity diverted and land cost	- 4
7	Toxic leaching prevented	56
8	Ash buried	- 1,185
	Net Contribution	3,229

Source:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Notes: 1983 U.S. $; annual emergy flow was divided by 1983 emergy/$ ratio for U.S., 2.4 E12 sej/$.
With incineration, landfill is 4% of items in appendix 25.

1. Item 1 and 2 in appendix 26

2. 39% of electricity yield in line 28 of appendix 30

3. Sum of items 1 and 2

4. Item 4 in appendix 26

6. 4% of items 2 and 3 in appendix 25

7. Item 3 in appendix 26

8. 4% of total ash(13 E6 T) = 0.52 E6 T
   emergy of solid waste, sum of items 1-12 from appendix 30 = 6.4 E22 sej/y

   Transformity of ash:
   (6.4 E22 sej/y)/(13 E6 T * 0.9E6 g/T) = 5.47 E9 sej/g
   4% of ash: (0.52 E12 g)(5.47 E9 sej/g)/(2.4 E12 sej/$) = 1185 E6 $

Appendix 29

Annual Macroeconomic Values with Option V,
Reuse, Compost, and Disperse

Note	Item	Million $/y
1	Recyclables including copper and zinc	9,560
2	Nutrients in Materials	13+
3	Toxic leaching prevented	+56
4	Reuse and recycling contribution	9,719
5	Composting cost	-203
6	Dispersal costs	-259
7	Land productivity diverted	-18
	Net contribution	+9,239

Source:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Notes: 1983 U.S. $; annual emergy flow was divided by 1983 emergy/$ ratio for U.S., 2.4 E12 sej/$. After recyclables were removed, shredded refuse from plant in Gainesville, Florida was used to plant pine forest with exceptional growth. Final disposal becomes a plus.

1. Item 1 and 2 in appendix 26

2. Assumed 0.1%

3. Item 4 in appendix 25

4. Sum of items 1 and 2

5. Estimate from an engineering consultant

6. Dispersal costs assumed same as collection costs. Item 15, appendix 25

7. Material spread on land where it contributes to fertility. Estimate 3 years of lowered productivity during transition. After 3 years land continues for forest or other production, stimulated by compost addition. Land is not purchased but arrangements made with private owners, timber companies, etc. to receive the fertilizing compost at no cost to them. 5.062 E6 tons

compostable: bulk density 0.1 g/cm^3; area required if spread 5 inches deep:
$(5.062\ E6\ tons)(0.9\ E6\ g/ton)/(0.1\ g/cm^3)/(13cm\ deep)/(1E4\ cm^2/m2) = 3.79\ E8\ m^2$
$(3.79\ E8\ m^2)/4.05\ E3\ m^2/ac) = 93{,}580$ acres in transition

Land production half during 3 year transition:
$(0.5)(3.79\ E8\ m^2)(3\ y)(1\ m\ transpired)(1\ E6\ g/m^3)(5\ J/g) = 2.84\ E15\ J/y$
$(2.84\ E15\ J/y)(1.5\ E4\ sej/J)/(2.4\ E12\ sej/\$) = 17.75\ E6\ \$/y$ macrovalue

Appendix 30

Annual Rates of Municipal Solid Waste Disposal in Texas

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (E9 1983 US$)
1	Food waste	8.229 E15 J	1.8 E6/J	1.481	6.17
2	Paper, cardboard	8.554 E16 J	2.15 E5/J	1.796	7.48
3	Plastics	3.534 E11 g	3.8 E8/g	0.013	0.056
4	Textiles	4.115 E15 J	3.8 E6/J	1.564	6.51
5	Rubber	5.889 E10 g	4.3 E9/g	0.025	0.104
6	Leather	1.029 E15 J	8.6 E6/J	0.88	3.68
7	Yard-wood trimmings	2.071 E16 J	4.3 E3/J	0.0089	0.037
8	Glass	9.423 E11 g	8.44 E8/g	0.079	0.33
9	Ferrous metals	9.423 E11 g	9.18 E8/g	0.086	35.8
10	Copper & Zinc Alloys	0.236 E11 g	6.77 E10/g	0.16	0.67
11	Aluminum	9.423 E10 g	1.63 E10/g	0.154	0.64
12	Dirt, Miscellaneous	4.712 E11 g	1.79 E9	0.084	0.35
13	Land production	7.29 E14 J	1.54 E4/J	0.00112	0.0047
14	Land cost	1.87 E7 $	2.4 E12/$	0.0043	0.018
15	Collection cost	6.65 E8 $	2.4 E12/$	0.160	0.67
16	Collection fuel	1.386 E15 J	6.6 E4/J	0.00915	0.038
17	Incineration cost	2.022 E8 $	2.4 E12/$	0.048	0.20
18	Separation cost	1.607 E9 $	2.4 E12/$	0.386	1.61
19	Recycling cost-paper	8.57 E7 $	2.4 E12/$	0.020	0.086
20	Recycling cost-glass	2.078 E7 $	2.4 E12/$	0.0050	0.021
21	Recycl. cost-aluminum	4.16 E7 $	2.4 E12/$	0.010	0.041
22	Recycl. cost-ferrous	1.455 E8 $	2.4 E12/$	0.035	0.146
23	Composting costs	2.025 E8 $	2.4 E12 sej/$	0.049	0.20
24	Dispersion cost	2.59 E8 $	2.4 E12 sej/$	0.062	0.26

Appendix 30 (continued)

Annual Rates of Municipal Solid Waste Disposal in Texas

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E22 sej)	Macroeconomic value (E9 1983 US$)
25	Nutrient value in compost	2.24 E9 g/y	1.41 E10 sej/g	0.032	0.13
26	Air pollution, PCB's	7.673 E5 g			
27	Groundwater toxics	1.18 E4 g			
28	Incinerator electric.	1.478 E16 J	1.59 E5/J	0.0235	0.098

Sources:

HDR-Tech Serve, Pete Golde, Engineering Consultant. 1987.

Schwarz, Stephen and C. Brunner. Energy and Resource Recovery from Waste. Park Ridge, N.J.: Noyes Data Corp. 1983.

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, The University of Texas at Austin, LBJ School of Public Affairs, pp. 235-255. 1986.

Notes: Emergy flow in column 3 was divided by 2.4 solar emjoules/$ for U.S. in 1983. The quantities of wastes per year for Texas are from appendix 31.

1 (1.95E6 T food waste/y)(4.0E6 BTU/T)(1055 J/BTU)

2 (5.71E6 T paper/y)(14.2E6 BTU/T)(1055 J/BTU)

3 (.39E6 T plastic/y)(907185 g/T)

4 (.26E6 T textiles/y)(15E6 BTU/T)(1055 J/BTU)

5 (.065E6 T rubber/y)(907185 g/T)

6 (.065E6 T leather/y)(15E6 BTU/T)(1055 J/BTU)

7 (1.818E6 T wood & yard/y)(10.8E6 BTU/T)(1055 J/BTU)

8 (1.039E6 T glass/y)(9.08E5 g/Y)

9 (1.039E6 T ferrous/y)(9.08E5 g/T)

10 (.026E6 T copper and zinc/y)(9.08E5 g/T)

11 (.104E6 T aluminum/y)(9.08E5 g/T)

12 (.519E6 T dirt/y)(9.08E5 g/T)

13 (1800 acres/y)(20 y/acre)(4.05E3 m^2/acre)(1 m transpiration/yr) (1E6 g/m^3)(5 J/g) = 7.29 E14 J/yr

14 (1800 acres/y)($10,000 acre), based on Austin case

15 ($51.18/T)(13E6 T/y), based on Austin case.

16 (8543 bbl/y)(5.25E6 BTU/Bbl)(1055 J/BTU), based on Austin case; see note that follows; (13E6/.443E6) = TX fuel consumed.

17 ($8E7 capital cost/ 40 year life) + ($4.9E6 O & M)/y, based on Austin case = ($6.9E6)(29.3)

18 ($202.86/ton of recyclables)(7.92E6 T/available recyclables), based on Austin case - recycling program budgets / tons of recylables collected.

19 ($15/T newspaper)(5.713E6 T); see note that follows.

20 ($20/T glass)(1.039E6 T); see note that follows.

21 ($400/T aluminum)(.104E6 T); see note that follows.

22 ($140/T ferrous/steel)(1.039E6 T)

23 ($40/T) (phone estimate from Eng. Consultant, Pete Golde, HDR-Tech Serve, Dallas, TX.)(5.062E6 T/y)

24 Assume equal to collection cost per ton: ($51.18/T)(5.062E6 T)

25 (Est. .001 phosphorus)(1.948E6 + .519E6T in items 1 & 12)(2.467E6 T)(9.08E5 g/T)

26 (2.44 lb/T sulfur acids)(Schwarz & Brunner, 1983): (2.44 lb/T)(454 g/lb)(13E6 T)

27 (Estimated .00001 leakage)(est. .0001 toxics)(13E6 T) = .013 T see note that follows; (.013 T)(9.08E5 g/T) = 11804 g

28 (140.139E6 KWH/y, Austin case, in note that follows) (3.412E3 BTU/KWH)(1.055E3 J/BTU)(29.3); see assumption #8)

Note: Assumptions for Calculations in Appendix 30:

1. Land costs for landfills in large urban areas in Texas will be similar to Austin costs. Information on city of Austin Recycling Program from interview with Richard Abramowitz, City of Austin, TX, Recycling Program.

2. Collection costs per ton in other Texas cities are comparable to Austin costs.

3. Amount of fuel needed for collection is directly proportional to the quantity of MSW produced, and is comparable in other urban areas to the Austin consumption rate.

4. Costs of incinerators will be comparable to Austin case, and will be proportional to quantity of MSW produced.

5. Cost per ton of separating recyclables through a voluntary program will be comparable for other Texas cities, and will be proportional to quantity of MSW produced.

6. Cost of recycling is assumed to be reflected in the prices paid for recyclables.

7. 100 percent of recyclables are recoverable; adjustments can be made based on lower percentages - 25 percent on paper, 75 percent on metals and glass.

8. Amount of electricity energy available from incinerating municipal solid waste is proportional to the amount of MSW burned.

9. Toxics remain in incinerated ash and are still likely to leak.

10. Toxics estimate based on IF 1/1000 of 1 percent of materials lead into groundwater from landfills, and IF 1/100 of 1 percent of materials in landfills are water soluble toxic or hazardous substances, then this amount of material will leak.

Appendix 31

Annual Rates of Solid Waste Production

Component	Person (lbs)	Austin (E3 tons)	Texas (E6 tons)	U.S. (E6 tons)
Food waste	274	66.4	1.95	31.5
Paper and cardboard	803	194.7	5.7	92.4
Plastics	55	13.2	0.39	6.3
Textiles	36	8.9	0.26	4.20
Rubber	9	2.2	0.065	1.05
Leather	9	2,2	0.065	1.05
Yard, wood	255	62.0	1.82	29.4
Glass	146	35.4	1.04	16.8
Ferrous	146	35.4	1.04	16.8
Nonferrous (copper etc.)	4	0.89	0.02	0.42
Nonferrous (aluminum)	15	3.54	0.10	1.68
Dirt, misc.	73	17.70	0.52	8.40
TOTALS	1825	442.53	12.97	210.

Source:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Appendix 32

Composition and Energy Values of Municipal Solid Waste

Component	Typical % by weight	BTU/lb.	BTU/ton
Food waste	15	2,000	4,000,000
Paper and cardboard	44	7,100	14,200,000
Plastics	3	14,000	28,000,000
Textiles	2	7,500	15,000,000
Rubber	0.5	10,000	20,000,000
Leather	0.5	7,500	15,000,000
Wood and yard trimmings	14	5,400	10,800,000
Glass	8	60	120,000
Ferrous metals	8	300	600,000
Copper/zinc alloys	0.2	-	-
Aluminum	0.8	-	-
Dirt, ashes, miscellaneous	4	3,000	6,000,000

Source:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Appendix 33

Municipal Solid Waste Quantities

Component	Pounds per day	Tons per year
Per person	5	0.91
Austin, Texas #	2.425E6	0.44E6
Texas	71.15E6	13.0E6
U.S.A	1,150.0E6	209.9E6

Source:
Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public affairs, The University of Texas at Austin. 1986. pp. 235-255.

Note: Austin information from interview with Joe Word, City of Austin, Solid Waste Services.

Appendix 34

Total Wastes in Texas

Component		Tons per year	Percentage of total
AIR:	Particulates	277,516	
	Volatiles, VOC's	574,448	
	Sulfur acids, SOX	1,870,782	
	Nitrogen acids, NOX	1,558,070	
	Carbon monoxide, CO	1,130,658	
	Total air wastes	5,411,474	6.7
SOLID:	Industrial	62,800,000	77.3
	Municipal	12,984,145	16.
	Total solid wastes	75,784,145	93.3
WATER:	Industrial	7,887	
	Municipal	37,041	
	Total suspended solids	44,928	0.06
TOTAL wastes in Texas		81,240,547	100.

Sources:

Van der Loop, B. "Solid Waste and Recycling." Unpublished student report for Policy Research Project course, LBJ School of Public Affairs, The University of Texas at Austin. 1986. pp. 235-255.

Texas Dept. of Health, 1981.

Appendix 35

Emergy Flows per Acre for an Average Large Texas Farm, 1982
Gross Annual Sale Category: $100,000 and over

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E12 sej/y)	Macroeconomic value (1983 US $)
			PRODUCT FLOWS		
PRODUCTION					
1	Cattle	7.3E8 J	1.73 E6/J	1263.	485.
2	Cotton	13.6E5 J	8.6 E5/J	1.17	0.45
3	Grain	2.48E9 J	8.6 E4/J	213.3	82.0
	Total production			1633.25	567.45
PURCHASED INPUTS					
	Commercial fertilizer:				
4	Nitrogen	1.57E4 g	4.19E9/g	65.82	27.43
5	Phosphate	1.57E4 g	1.41E10/g	221.5	92.29
6	Potassium	1.57E4 g	5E8/g	7.85	3.27
	Total fertilizer			295.17	122.99
7	Fuel	7.03E8 J	6.6E4/J	46.40	19.33
8	Electricity	6.63E7 J	15.9E4/J	10.54	4.39
9	Machinery, equipment	.001 T	6.7E15/T	6.7	2.79
10	Livestock, poultry	31.29E7 J	2E6/J	625.8	260.75
11	Feeds	2.17E9 J	6.8E4/J	147.72	61.55
	Total purchased inputs			1132.33	471.80
ENVIRONMENTAL INPUTS					
12	Transpired waters	16.2E9 J	1.54E4/J	249.48	103.95
			MONEY FLOWS		
DOLLAR INCOME					
	Gross annual sales:				
13	Rec´d from cattle	82.47 $	2.4E12/$	197.93	82.47
14	Rec´d from cotton	9.20 $	2.4E12/$	22.08	9.20
15	Rec´d from grain	24.93 $	2.4E12/$	59.83	24.93

Appendix 35 (continued)

Emergy Flows per Acre for an Average Large Texas Farm, 1982

Gross Annual Sale Category: $100,000 and over

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E12 sej/y)	Macroeconomic value (1983 US $)
	Total gross sales	116.49 $	2.4E12/$	279.58	116.49
16	Ag-related sales of services	0.31 $	2.4E12/$	0.74	0.31
17	Gov´t subsidies	4.44	2.4E12/$	10.66	4.44
	Total ag-related inc.	121.24	2.4E12/$	290.98	121.24
	DOLLAR EXPENSES				
18	Loan interest	5.82	2.4E12/$	13.97	5.82
19	Taxes	2.91	2.4E12/$	12.12	2.91
20	Hired labor	6.08	2.4E12/$	14.59	6.08
21	Contract labor	0.96	2.4E12/$	2.32	0.96
22	Fuel	5.55	2.4E12/$	13.32	5.55
23	Fertilizer	3.41	2.4E12/$	8.18	3.41
24	Livestock & poultry	35.00	2.4E12/$	84.00	35.00
25	Feed	21.80	2.4E12/$	52.32	21.80
26	Chemicals not fertilizer	2.36	2.4E12/$	5.66	2.36
27	Custom work, machine rental	1.49	2.4E12/$	3.58	1.49
28	Electricity	1.31	2.4E12/$	3.14	1.31
29	Machinery, equipment	3.26	2.4E12/$	7.82	3.26
	Total expenses	89.95	2.4E12/$	217.05	90.44
	Income - expenses	30.80		73.93	30.80

Sources:

Snoddy, J. "Farm Size and Agricultural Change." Unpublished student report for Policy Research Project course, the University of Texas at Austin, LBJ School of Public Affairs, pp. 235-255. 1986.

Texas A & M University, Professor Hayenga, tax specialist, Agricultural Economics Dept., personal communication. 1986.

U.S. Department of Agriculture (USDA). Crop Reporting Board. Statistical Reporting Service. Agricultural Prices: Annual Summary 1982. Washington, D.C. 1982.

Notes: Total number of farms: 13,769; average size of farm: 4,284 acres. To calculate macroeconomic value, emergy flow in column 5 was divided by 2.4 E12 solar emjoules/$ for U.S. in 1983.

1. Production. 1982: average market value of products sold per farm: $499,030 ; percentage of value of production attributed to major commodities: cattle - 70.8%, cotton - 7.9%, grain - 21.4%; price of commodities same as small farm (table 14.1, #1).

Cattle:
($499,030)(.708)/($59.9/cwt)(100lbs/cwt)(.4536kg/lb)(2.82kcal/g)(4186J/kcal) /(4,284ac) = 7.3E8 J/y

2. Cotton:
($499,030)(.079)/($51.3/bu)(.4535kg/lb)(4kcal/g)(4186J/kcal)/(4284ac) = 13.6E5J/y

3. Grain: ($499,030)(.214)($3.36/bu)(23.94kg/bu)(3.345kcal/g)(4186J/kcal)/ (4,284ac) = 2.48E9 J/y

4. Commercial fertilizer. 1982: $14,589 (table 14.1, #4)

Nitrogen: ($14,589)(.30)(/(177/T/3)(2000lb/T)(.45kg/lb)(1000g/kg)/(4,284ac) = 1.57E4 g/y

5. Phosphorus, 12:12:12: fertilizer, same as #4.

6. Potassium, same as #5.

7. Fuel. 1982: $23,767 (table 14.1 #7)

($23,767)(1.18/gal)(2.381E-2bbl/gal)(6.28E9J/bbl)/(4,284ac) = 7.03E8 J/y

8. Electricity. 1982: $5,601 (table 14.1 #8)

($5,601)($.071/KWH)(3.6E6J/KWH)/(4,284ac) = 6.63E7 J/y

9. Machinery and equipment. 1982: average number of machinery type per large farm: motor truck 4, tractor 4, equipment 2 (table 14.1 #9)

(4)(12000lb)+(4)(12,500lbs)+(2)(21000lb) = 70 T
(70T)/(4284ac)/(15y life) = .001 T/y

10. Livestock & poultry. 1982: $149,941 (table 14.1 #10)

($149,941)/(4,284ac)($59.90/cwt)/(100lb/cwt)/(.45kg/lb)/(1000g/kg)(2.82kcal/g) = 31.29E7 J/y

11. Feed. 1982: $93,426 (table 14.1 #11).

($93,126)/(4,284ac)/(3.364/bu)(.9453bu)(23.94kg/bu)(3.345kcal/g)(4186J/kcal) = 2.17E9 J/y

12. Environmental (table 14.1 #12).

13. Gross annual sales (table 14.1 #13).

Cattle: ($199,030)(.708)/(4,284ac) = $82.47/y

14. Cotton: ($499,030)(.079)/(4,284ac) = $9.20/y

15. Grain: ($499,030)(.217)/(4,284ac) = $24.93/y

16. Ag related sales of service. 1982: $1,332, compiled from (US, 1982).

($1,332)/(4,284) = $0.31/y

17. Gov´t subsidies. (table 14.1 #17).

($918,226,000)(.285)/(13,769)/(4,284ac) = $4.44

18. Loan interest. 1982: $2.5E4 (US, 1982)

($2.5E4)/(4,284ac) = $5.82/y

19. Taxes. Approximate amount of taxes paid by farmers of large farms $1.25E4 (Professor Hayenga, tax specialist, Agricultural Economics Dept., Texas A & M Univ., telephone interview, May, 1986.)

($1.25E4)/(4,284ac) = $2.91/y

20. Hired labor. 1982: $2.6E4 (US, 1982).

($2.6E4)/(4,284ac) = $6.08

21. Contract labor. 1982: $4.11E3 (US, 1982).

($4.11E3)/(4284ac) = $0.96/y

22. Fuel. average expense for petroleum products, $2.38E4 (#7).

$2.38E4)/(4284ac) = $5.55/y

23. Fertilizer. See footnote #4 for average fertilizer expense.

($14,589)/(4284ac) = 3.41/y

24. Livestock & poultry. (#10)

($149,941)/(4284) = $35./y

25. Feed. (#11)

($93,426)/(4284ac) = $21.80/y

26. Chemicals not fertilizer. $10,112 (US, 1982)

($10,112)/(4284ac) = $2.36/y

27. Custom work, machine rental. $6377 (US, 1982).

($6377)/(4284ac) = $1.49/y

28. Electricity. (#8)

($5,601)/(4284ac) = $1.31

29. Machinery. $140,282/4184/15 years life = $1.62 cost/acre/y
Maintenance. $140,282/4284(.05) = $1.64 cost/acre/y
($1.62)+($1.64) = $3.26

Appendix 36

Emergy Evaluation of Texas Cattle, Grain, and Vegetable Production in 1983

Note	Item	Raw Units	Transformity (sej/J)	EMERGY (E20 sej/y)	Macroeconomic value (1983 U.S $ E9 $/y)
1	Cattle and Calves	2.98 E16 J/y	1.73 E6	515	19.8
2	Grains	1.49 E17 J/y	8.6 E4	128	4.9
3	Vegetables	4.29 E15 J/y	2.6 E5	11.1	0.43

Source:

Texas Department of Agriculture. Field Crop Statistics, Austin, Texas. 1982.

Notes:

1. Cattle and Calves 1983; 5.555 E9 pounds production (Texas Livestock Dairy and Poultry Statistics for 1983, Texas Department of Agriculture, 60 pp)

(5.555 E9 lbs)(454 g/lb)(2.82kcal/g)(4186 J/kcal)= 2.98 E16 J/y

Transformity of beef products estimated from appendix 35 as ratio of 0.89 of the solar emergy of inputs (beef 89% of yield emergy) to energy in products: (0.89 *(1132 + 291) E12 sej/yr)/(7.3 E8 J/yr) =1.73 E6 sej/J

2. Grains corn, 104,760,000 bushels; barley, 2,476,000 bushels; oats, 10,730,000 bushels; rye, 450,000 bushels; winter wheat, 161,000,000 bushels; sorghum, 88,200,000 pounds CWT; rice, 13,805,000 pounds CWT. (Texas Field Crop Statistics for 1984, Texas Department of Agriculture, 100 pp.)

(11.95 E12 grams/year)(0.9 dry)(13826 J/gram) = 1.49 E17 J/y

3. Vegetables, fruits: production in 1982, 1.74 E9 pounds/y (Texas vegetable Statistics for 1985, Texas Department of Agriculture, 44 pp.)

(2.82 E9 lb/y)(.2 dry)(454 g/lb)(4 kcal/g)(4186 J/kcal) = 4.29 E15 J/y

Transformity estimated as solar emergy in rain on acreage:
(301,800 acres)(2.1 ft/y rain)(1233 m3/ac-ft)(1E6 g/m3)(5 J/g) = 3.9E 15 J/y
(3.9 E15 J/y)(1.54 E4 sej/J) = 0.6 E20 sej/y

plus services estimated from cash receipts (1982): $4.07 E8/y
($4.07 E8)(2.6 E12 sej/$) = 10.5 E20 sej/yr

Emergy inputs (0.6 + 10.5) E20 sej/y = 11.1 E20 sej/y

Solar Transformity = 11.1E20 sej/y/4.29 E15 J/y = 2.6 E5 sej/J

Notes for column 3 in table 7.2: Potential for attracting investments that bring in resources from the main economy estimated as 7 times the macroeconomic value of the water used, 2 feet/y on areas: cattle-calves, 1.38 E8 acres; grain, 2.27 E7 acres; vegetables, 2.0 E5 acres.

Macroeconomic values of water as environmental input:
Cattle:(1.38 E8 acres)(4.05 E^{3}m^2/acre)(.6 m rain)/y)(1 E6 g/m^3)(5 J/g)(1.54 E4 sej/J)/(2.6 E12 sej/$) = 9.93 E9 $/y

Grain:(2.27 E7 acres)(4.05 E3m^2/acre)(.6 m rain)/y)(1 E6 g/m^3)(5 J/g)(1.54 E4 sej/J)/(2.6 E12 sej/$) = 1.63 E9 $/y

Vegetables:(2.0 E5 acres)(4.05 E3m^2/acre)(.6 m rain)/y)(1 E6 g/m^3)(5 J/g)(1.54 E4 sej/J)/(2.6 E12 sej/$) = 0.014 E9 $/y

Appendix 37

Calculations of Advantage to Texas of Exports and Imports

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1. Grain Sales: (203 E5 tons/y)($134/ton) = 2.72 E9 $/y
Macroeconomic value: (203 E5 Tons/y)(1E6 g/ton)(3.17 kcal/g)(4186 J/kcal)(8.6 E4 sej/j)/(2.6 E12 sej/$) = 8.9 E9 $/y

2. Mexican imported vegetables, sales: (285 E6 $/y)(1E6 g/ton)(1.26 E4 J/g)(2.6 E5 sej/j)/(2.6 E12 sej/$ * 100 $/ton) = 3.59 E9 $/y

3. Export of oil and gas from Mexico to U.S., much of it to Texas.
(273 E6 cu ft/day)(1.1E6 J/cu ft)(4.8 E4 sej/J)(365 d/y) = 0.53 E22
(250 E6 bbl/y)(6.3 E9 J/bbl)(5.3 E4 sej/J) = 8.3 E22
Refined: (42 T/day)(365 d/y)(1 E6 g/T)(3.7 E4 J/g)(6.3 E4 sej/J)=.0037
Oil and gas export: 8.8 E22 sej/y
Macroeconomic value: (8.8E22 sej/y)/2.6 E12 sej/$) = 3.38 E10 $/y
Oil sales, 17.6 E9 $/y.

Appendix 38

Preliminary Emergy Evaluation of Texas Upland Cotton in 1981

Note	Item	Raw Units	Transformity (sej/unit)	EMERGY (E20 sej/yr)	Macroeconomic value (1983 U.S.$ E9 $/yr)
1	Rainfall	8.75 E16 J/y	1.54 E4/J	13.5	0.52
2	Fertilizer	1.45 E11 g/y	5.55E9/g	8.1	0.31
3	Fuels	8.61 E15 J/y	6.0 E4/J	5.2	0.2
4	Electricity	1.05 E15 J/y	1.59 E5/j	1.67	0.064
5	Machinery	--	--	12.9	0.50
6	Pesticides	3.5 E14 J/y	1.97 E7/J	69.0	2.65
7	Services	1.26 E9 $/y	2.6 E12/$	32.8	1.26
8	Total inputs			142.37	5.36
9	Yield	1.90 E16 J/y	8.6 E5	142.37	5.36

Sources:

Bosch, Gisele. Solar Equivalents of raw and refined iron, steel, and end-products. Appendix A12, pp. 430-443 in Energy Analysis Overview of Nations ed. by H.T. Odum and E.C. Odum, International Institute for Applied Systems Analysis, Working Paper WP-82-83. 1983.

Texas Department of Agriculture. Field Crop Statistics, Austin, Texas. 1982.

U.S. Department of Agriculture, Economic Research Service, November 1985 IOS-6.

Notes: Cotton and cottonseed 14.88% of total agricultural earnings in 1981; 0.145 used as fraction to evaluate fuel and electricity use.

1. Rain used:
(7.2 E6 Acres harvested)(.6 m water/y)(4.05 E3 m^2/acre)(1E6 g/m^3)(5 J/g) =
= 8.75 E16 J/y Gibbs Free energy

2. Fertilizer use, 1981, 3.076 E6 tons/y in all agriculture; 5.2 % of acreage in cotton
(3.076 E6 Tons/y)(.052)(9.07 E5 g/ton) = 0.145 E12 g/y

3. Fraction that cotton is of total agricultural earnings: 0.145; total agricultural fuel use in appendix 39: 5.94 E16 J/y
(0.145)(5.94 E16 J/y) = 8.6 E15 J/y

4. Fraction that cotton is of total agricultural earnings: 0.145; total agricultural use of electricity: 7.22 E15 J/y

(0.145)(7.22E15 J/y) = 1.05 E15 J/y

5. 7.5 E9 \$/y for machinery; 0.145 due to cotton;
Ratio of emergy in finished machinery to \$ received from German machinery analysis (Bosch, 1983):
(15.6E22 sej)/ (13.1 E10 \$/y) = 1.19 E12 sej/\$

(0.145) (7.5 E9 \$/y)(1.19 E12 sej/\$) = 12.9 E20 sej/y

6. Pesticides 18,287,000 pounds used in 1982 (Inputs, U.S. Deparment of Agriculture, Economic Research Service, November, 1984 IOS-6, 37 pp)
(1.83 E7 lbs/y)(454 g/lb)(10 kcal/g)(4186 J/kcal) = 3.5 E14 J/y

7. Services as money received:
1981 upland cotten
7,200,000 acres harvested
376 pounds yield per acre
5,645,000 bales production (480 pounds/bale)
price \$.465/pound
(1982 Texas Field Crop Statistics, Texas Department of Agriculture.)

(7.2 E6 Acres/y)(376 lb/acre)(\$.465/pound in 1981) = 1.26 E9 \$/y

8. Sum of emergy inputs was used to calculate transformity in footnote (9).

9. Yield
(7.2 E6 Acres/y)(376 lb/acre)(454 g/lb)(3.7 kcal/g)(4186 J/kcal) =
= 1.90 E16 J/y

Transformity calculated as sum of inputs from footnote 7 divided by energy of yield: (142.37 E20 sej/y)/1.66 E16 J/y = 8.6 E5 sej/J

Appendix 39

Emergy Evaluation of Texas Agriculture in 1983

Note	Item	Raw Units	Transformity (sej/j)	Emergy (E20 sej/y)	Macroeconomic value (1983 U.S. $ E9 $/y)
1	Rain used	1.98 E18 J/y	1.54 E4	304.9	11.7
2	Services	8,970. E6 $/y	2.4 E12	215.3	8.3
3	Fuels	5.94 E16 J/y	6.0 E4	35.6	1.4
4	Electricity	7.22 E15 J/y	1.59 E5	11.5	0.44
5	Fertilizer	2.33 E12 g/y	5.55 E9	129.3	5.0
6	Pesticides	4.4 E13 J/y	1.97 E7	8.7	0.33
	Total				27.7

Sources:

Odum, H.T. Energy Analysis of the Environmental Role in Agriculture. Chapter 3, pp. 24-51 in Energy in Agriculture, ed. by G. Stanhill. New York: Springer-Verlag. 1984.

Texas Department of Agriculture. Field Crop Statistics, Austin, Texas. 1982.

Texas Department of Agriculture (T.D.A.) and U.S. Department of Agriculture. Cash Receipts, Prices Received and Paid by Farmers, Washington, D.C. 1982.

Notes:

1. Texas farm area in 1982, 138,400,000 acres in farms of 748 acres average size; Total fertilizer used, 2,565,779 tons
(1982 Texas Field Crops Statistics, Texas dept. of Agriculture, 104 pp)

Rain: footnote 2 in appendix 9 3.66E8 acre-feet,2.23 E18J/y
(2.23 E18 J/y)(0.89 evapotranspired) = 1.98 E18 J/y

2. Cash receipts from all commodities, $ 8,970,399,000
(Texas Agricultural Cash Receipts and Price Statics for 1985, Texas Department of Agriculture, 40 pp.)

3. Fuel use in 1982:
gasoline and gasahol, $185,805,000;
($185.8 E6 /y)(1.30 E8 J/gallon) / ($1.18/gallon) = 2.05 E16 J/y
diesel, $233,210,000;
($233.2 E6 $/y)(44.5 E6 J/liter)(3.75 Liter/gallon)/($1.00/gallon) =
= 3.89 E16 J/y
Total energy: (2.05 + 3.89) E16 J/y = 5.94 E16 J/y

4. Electricity, $128,106,000.
($128.1 E6/y)(3.61 E6 J/kwh)/($.064/kwh) = 7.22 E15 J/y

5. For mixed fertilizer. 1.61 E15 SEJ/2.9 E5 g (Odum, 1984) = 5.55 E9 sej/g
(2.567 E6 tons/y)(9.07 E5 g/tons) = 2.33 E12 g/y

6. Pesticide use in 1982, 208.7 E6 $;
(208 E6 $/y)(4.2 E6 J/kg)/$20/kg = 4.4 E13 J/y

price of fuels in 1983, gasoline prices for 1983, $1.18/gallon; diesel, $1.00/gallon. (Inputs, outlook and situation report, Economic Research Service, U.S. Dept. of Agriculture, Nov. 1984 37 pp)

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