EMERGY EVALUATIONS OF THE UNITED STATES CIVIL WAR

By

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"If mathematics can be used to predict the intensity and rate of spread of wildfires in the future, why can't the direction of the analysis be reversed in order to reconstruct the characteristics of important fires of the past? Or why can't the direction be reversed from prophecy to history?"

Norman Maclean,
Young Men & Fire

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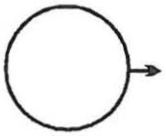
LIST OF ABBREVIATIONS

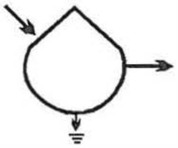
bbl	barrels
CSA	Confederate States of America
CSN	Confederate States Navy
FAO	Food and Agriculture Organization of the United Nations
GBCSO	Great Britain Central Statistical Office
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
ORUCA (*series-volume*)	Official Records of the Union and Confederate Armies, (U.S. War Department, 1881 - 1901)
sej	solar emjoules
UKCSO	United Kingdom Central Statistical Office
USCGS	United States Coastal and Geodetic Survey
USDA	United States Agriculture Department
USCO	United States Census Office
USDC	United States Department of Commerce
USN	United States Navy
USPO	United States Patent Office
USTD	United States Treasury Department

SYMBOLS OF THE ENERGY CIRCUIT LANGUAGE (ODUM, 1971; 1983)

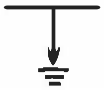
ENERGY CIRCUIT: a flow of energy, often with a flow of material.



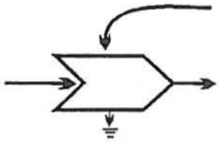
SOURCE: outside source of energy; a forcing function.



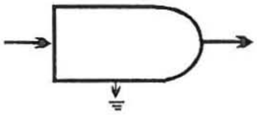
STORAGE: a compartment of energy storage within the system storing a quantity as the balance of inflow and outflows.



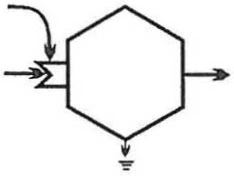
HEAT SINK: dispersion of potential energy into heat that accompanies all real transformation processes and storage.



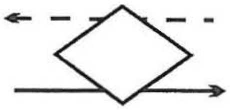
INTERACTION: process which combines different forms of energy flows or material flows to produce an outflow in proportion to a function of the inflows.



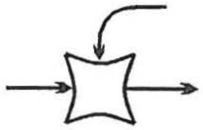
PRODUCER: unit that collects and transforms low-quality energy under control interactions of higher quality flows.



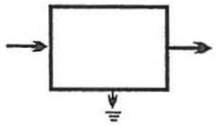
CONSUMER: unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve flow.



TRANSACTION: a unit that indicates the sale of good or services (solid line) in exchange for payment of money (dashed line).



SWITCHING ACTION: symbol that indicates one or more switching functions where flows are interrupted or initiated.



BOX: miscellaneous symbol for whatever unit or function is labeled.

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EMERGY EVALUATIONS OF THE UNITED STATES CIVIL WAR

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Chairman: Howard T. Odum
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The hypothesis of this study is that various kinds of power (energy flows) exert influences in history and that they exert these influences in proportion to their respective values of "emergy," a concept that measures the work of humans and the environment on a common basis. Emergy is defined as the sum of the available energy used directly and indirectly in the production of a given product. This dissertation used emergy to develop and evaluate overview models of the United States and its civil war. Everything contains available energy and therefore has an emergy value. Thus, all influences and effects can be measured and compared on the common basis of emergy allowing tests of the hypothesis.

Emergy evaluations of the United States and Great Britain in the nineteenth century characterized the environmental support of the countries and their citizens and the dollar and pound's nineteenth-century purchasing power relative to natural resources and environmental services. The evaluations found the U.S. system grew at a steady rate through the period from 1850 to 1870, supporting the hypothesis that the Civil War was not a catalyst for the U.S. industrial revolution.

In 1860, the emergy embodied in slaves was 3 times the entire annual emergy support of the United States, an indication of the importance of the slavery issue. The emergy use and destruction of the War was 1.3 to 2.7 times the U.S. 1860 emergy support. The Civil War was similar to twentieth-century wars, having a much higher emergy use than seventeenth-century wars, supporting the conclusion that it was the first "modern" war. The emergy of the effort required to wage the War exceeded the damage inflicted during the War in accordance with a general principle that was believed to derive from the pressure for optimum rather than maximum efficiency in warfare. Emergy was an important asset to historical study because emergy evaluated direct and indirect influences that were major factors in historical theories but that other analysis methods could not evaluate on a single basis.

CHAPTER 1
INTRODUCTION

The hypothesis of this study is that various kinds of power (energy flows) exert influences in history and that they exert these influences in proportion to their respective values of "emergy," a concept that measures the work of humans and the environment on a common basis. Emergy is defined as the sum of the available energy used directly and indirectly in the production of a given product. This dissertation used emergy to develop and evaluate overview models of the United States and its civil war (1861-1865). Everything contains available energy and therefore has an emergy value. Thus, all influences and effects can be measured and compared on the common basis of emergy allowing tests of the hypothesis.

Understanding the self-organization of systems, the processes and patterns resulting from this organization, and the relationship of all these to energy is a primary concern in the progress of science. Parts of the large-scale systems of environment and human economy are studied by many disciplines, but few principles are accepted regarding overall performance of these systems. Some fields of history deal with behavior of the larger earth systems over time, the pulsing rise and decent of human assets, organizations, or war and peace. Energy systems concepts of modeling and evaluation, first applied to smaller environmental systems, may provide new insights about human civilizations. Can the self-organization of the human economy be related to energy resources and the principles of maximum-power and maximum-empower?

The concepts of ecology and environmental science seem to cross readily into the historical fields. A common theme within environmental policy decisions might be called "human influenced environmental change." Many research efforts have been focused on quantifying these influences and changes, with cumulative impact assessments and global climate change studies prominent among the efforts. Inherent in these efforts is an idea that environmental change may affect the well being of humans and their societies. A companion to this human influence theme might be a biosphere influence theme, "environmental influenced human change." While themes of this category have several adherents, they can suffer from a problem of inadequate quantification. This study attempted to quantify and test the influence of biospheric, ecologic, and environmental factors on human societies and human systems by analyzing the potential contributions of the many environmental systems to human history using methods that measure all factors on a common scale.

Measures of Environmental Effort

Many methods have been proposed to measure environmental contributions to human societies or economies. There are, however, serious obstacles to obtaining meaningful measurements of both the effect of humans on their environment and the effect of the environment on humans. The obstacles arise because the effects take different forms. For example, there are the births and deaths of individual organisms, changes in ecosystem production, changes in genetic stocks and species diversity and richness, and changes in environmental impact.

One approach evaluates opportunity costs; the opportunities that no longer exists because something was affected or because resources were used to prevent an effect. Usually estimated as currency values, opportunity costs are the sum of benefits and losses as well as the materials, labor, and fuels required to alleviate effects. Ideally, data from environmental studies could be used to develop policies that optimize the benefits, losses, and investments in prevention methods so as to produce the highest net benefit to society. This requires, however, that the costs and benefits be accounted for in a common unit in order to compare the opportunity costs of different scenarios. The lack of such a common unit hinders both environmental policy formation (to deal with future events) as well as the study of human history (analyses of past events).

Prices or market values alone are not suitable measures of environmental contribution. Money is only paid for human services required to facilitate environmental use. Polanyi (1977) argued that it should never have been expected that money and .market forces would value things outside of markets like environmental contributions. He explained,

> the logical error was of a common and harmful kind: a broad generic phenomenon was somehow taken to be identical with a species with which we happen to be familiar. In such terms, the error was equating the human economy in general with its market form (a mistake that may have been facilitated by the basic ambiguity of the term *economic*). (Polanyi, 1977, p. 10)

Costanza and Farber (1984) recognized two broad groups of methodologies that used some type of "shadow price" to place losses and benefits in the same units. A shadow price is defined as a price placed on an cost or benefit external to the market and not traded by the market mechanism. Because all losses and benefits are not actively traded in existing markets, shadow prices must be used even when net benefits are calculated in monetary units. Costanza and Farber grouped these methodologies under the "willingness-to-pay" approach where some of the losses and benefits must be given subjective prices according to their relative benefit to society. They recognized another general group of methodologies, the energy evaluation approaches. One of these approaches evaluated embodied energy, the contribution or work of all inputs on a common basis (Odum, 1967; 1971). The approach was later modified and redefined as "emergy" (Odum 1986a; Scienceman; 1986). Emergy evaluation is among the few entirely quantitative evaluation methods for determining losses and benefits in the same units. It estimates values based upon inherent scientific concepts for the energy required to produce products and benefits rather than the subjective assignment of values.

Emergy Concepts

Emergy is defined as the sum of the available energy used directly and indirectly in the production of a given product (Odum, 1987a). "Emjoules," the units of emergy measurement, represent the sum of historical energy flows, and can be regarded as the memory of the energy (Scienceman, 1987), which enabled the production of the specified product. Solar emergy is the form used most frequently in emergy evaluations. The units of solar emergy are "solar emjoules" abbreviated "sej." Definitions of terms and concepts used in emergy evaluation are given in Table 1-1.

Because resources are limited, the use of a form of energy in a particular process precludes the use of that energy resource in an alternative process. These alternative uses are opportunity costs. The historical pattern of energy flows leading to a process accounts for the fitness of both the process and its products relative to alternative processes. Opportunity costs that distinguish between different forms of energy measure this relative fitness. When system designs are considered, these historical patterns are analogous to the "favorable variations" and "injurious variations" whose respective preservation and rejection Darwin (1979) labeled "natural selection" for species.

The general theory of emergy holds that natural biologic and geologic, and human economic systems all function according to principles involving energy, information, hierarchical organization, and processes that reinforce production. One of these principles, the maximum-power principle, is credited to Lotka (1922) and his predecessors (Martinez-Alier, 1987). It was expressed by Odum and Pinkerton (1955) as a "time's speed regulator" in which selection for maximum power output controlled the efficiency and persistence of system designs . This principle has since been refined as the "maximum-empower principle" (Scienceman, 1987). According to this principle, the system designs that prevail in nature are those that maximize emergy production, emergy inflow, and use. The specific theory that relates emergy as a potential factor in human history is the use of energies, materials, labor, and information that require large direct and indirect requirements (of energy, material, labor, and information) for their production is not a stable strategy or design unless the products have effects commensurate with the requirements for their production. Thus, as systems self organize, the impact and contribution of different energies,

Table 1-1. Emergy definitions and emergy evaluation terminology. Odum (1994) also gives definitions for emergy terminology.

Available Energy	Energy with the potential to do work.
Emmassity	Emergy per unit mass or specific emergy (Scienceman and El-Yousesef, 1993).
Emergy	The sum of the available energy used directly and indirectly in the production of a given product.
Emergy Investment Ratio	The ratio of the emergy brought into a system divided by the emergy of the feedbacks from the economy necessary to secure, mine, or harvest the emergy brought in.
Emergy-Money Ratio	The ratio of emergy flux to gross domestic or national product; used to estimate the emergy value of human services embodied in a product.
Emergy Signature	The distribution of emergy values among the energy flows into and out of, and from storages within a system during a given time period.
Emjoule	The unit measure of emergy.
Empower	The emergy value of a flow of available energy per unit time.
Energy Concentration or Quality	The potential of a unit of given form energy to do work relative to other forms of energy.
Maximum-Empower Principle	A principle by which system designs that prevail in nature are those which process energy flows so as to obtain maximum use for the flows' emergy values.
Maximum-Power Principle	A principle by which system designs persist because they maximize power.
Net Emergy Benefit	The emergy saved or not lost because a process was implemented, less the emergy required to implement that process.
Net Emergy Yield Ratio	Emergy value of a product divided by the sum the inputs from the economy (measured in emergy) used in producing the product.
Solar Emergy	Emergy measured in terms of solar energy. Solar emergy is expressed in solar emjoule (sej).
Solar Transformity	Solar emergy per unit energy expressed in solar emjoules per joule (sej/J).
Transformity	The total energy, measured in one form, required to produce one unit of energy of the given product.

materials, labor, and information become proportional to the emergy of their respective formation requirements (Sundberg et al., 1994a).

The distribution of the emergy values of the energy flows entering a system among the various flows and storages within a system forms the "emergy signature" of that system (Odum, 1976 (under a different name than emergy)). The "transformity" of a given energy is defined as the total emergy flow or empower required to produce one unit energy of the given product. It is measured in historical (or previous) flows of energy; the units of transformity are emjoules per joule of the specified energy form. Transformity reflects the resources required to make a unit of something and has therefore been suggested as a measure of unit value or wealth (Odum, 1976; 1987a).

Energies of different forms have different potentials to yield work. Available energy is the energy capable of yielding work, where work is defined as an energy transformation. Since most processes have an optimum loading and speed that maximize useful power transformation, the thermodynamic minimum (optimum efficiency; the maximum that is practical) is that which also maximizes power. The thermodynamic constraints establish minimum transformities that are the theoretical lower limits for transformities in the given process. A particular process (selected for optimum loading) may be judged as inefficient if its product has a higher transformity than an identical product produced by a second process (Odum, 1987a). Odum suggests that energy flows with large transformity differences cannot interact to yield the best output, but require intermediate processes. He cites as examples that human bodies cannot use sunlight as an energy source directly and that high technology ships are not effectively used in catching microscopic plankton for use as an human or livestock energy source.

Solar emergy, rather than coal or electrical emergy, is usually used because solar energy has the lowest transformity among the main sources of energy for the lithosphere. The other two main sources of earth emergy are radioactive and thermal heat energy resulting from the earth's formation and tidal energy. Equivalent solar emergy values must be estimated for these two energy forms according to the joules of each having equivalent effects. Odum (1987a; 1988; 1994) has suggested conversions based upon the comparison of: 1.) the contributions solar energy and gravitational forces to tidal processes; and 2.) the contributions of solar energy and asthenospheric thermal energy to geologic processes. Calculations from the data of Sclater et al. (1980) yielded relationships of 6100 sej/J emergy conversion for asthenospheric heat. Calculations from the data given by Monk and Macdonald (1960) and Miller (1966) yielded a 16800 sej/J emergy conversion for gravitational tidal energy. These two values may then be used as assumed transformities for asthenospheric heat and gravitational forces (Odum, 1994).

Emergy theory is based upon the fact that energy of some quality accompanies or is a component of everything, including materials, labor, and information (Odum, 1986a; 1987a; 1994). Boltzman (1905) and Lotka (1922), in describing this theory, suggested the struggle for existence was a competition for energy. Humans are unable to significantly increase the rate of emergy entering the biosphere in the form of solar radiation, planetary motion, and radiation from within the planet. The global rate of emergy use can be greater than the input from these three sources only when storages of previous emergy flows are used. Such storages include biomass, minerals, and fossil fuels.

Emergy as an Historical Method

Emergy and Human Society and Systems

It is hypothesized that various kinds of power exert influences in history and that they exert these influences in proportion to their respective empowers. Since empower is a measured quantity, it is possible to relate empower to the observed effects thus beginning to test the hypothesis. Traditionally the word "power" is loosely used for the ability of states, nations, institutions, and individuals to accomplish results. Thus one may speak of "economic power," "military power," "power of the press," " power of public opinion," or "power of kings." "Power" is more narrowly defined in science and engineering as the flow of useful energy per measured time, and measured in units like joules or calories per time (like watts which are joules per second). Since more than one form of energy is usually involved in real processes, the rate of emergy flow (empower) is used because it puts all forms on energy on a common basis. This basis is the requirement for the energy forms' generation. Sundberg emphasized that the theory that related emergy as a factor in human history was: the use of energies, materials, labor, and information that require large direct and indirect requirements (of energy, material, labor, and information) for their production is not a stable strategy or design unless the products have effects commensurate with the requirements for their production. Thus, as processes self organize, the impact and contribution of different energies, materials, labor, and information become proportional to the emergy of their formation requirements (Sundberg et al., 1994a).

The most basic tenet of the application of emergy evaluation to human history, economies, or public policy formation is that human systems are "natural" ecosystems and that humans and their systems are ultimately subject to the laws of ecosystems and physics. According to this tenet, the basic production-consumption model of ecosystems is also the model of economic systems except that the economic systems also have money circulation (Odum, 1988). This tenet is derived from the field of "general systems theory." Even though emergy is an historical index measuring previous energy flows or energy memory, the use of emergy as a tool in the study of human history as well as in public policy is grounded within general systems theory, not historical theory. General systems theory is a generalist field of study that seeks to benefit from general observations, theories, and techniques that have applications in several divisions of natural, social, and physical sciences. Lotka (1925) is generally credited as being the first to advance general systems theory by presenting simultaneous differential equations for the definition of general systems (Von Bertalanffy, 1955; Odum, 1983; Martinez-Alier, 1987).

Von Bertalanffy (1955; 1968) summarized the aims of general systems theory as recognizing: 1.) a general tendency towards integration in the natural and social sciences that seemed to be focused in a general theory of systems; 2.) that such a theory is an important technique in developing theories in the non-physical sciences; and 3.) that developing unifying principles of science that run "vertically" through the bodies of thought and theory of the individual sciences lead toward the goal of unity in science. Odum (1983) described a value of the general systems approach. He suggested the approach preventing the wasteful duplication of research efforts that occurred when many separate and isolated academic fields studied similarly constructed systems, and independently discovered and developed theories, models and laws that had already been discovered in other fields.

The basic thesis of Cottrell's (1955) study *Energy and Society* was "the amounts and types of energy employed condition man's way of life materially and set somewhat predictable limits on what he can do and how society will be organized" (p.23). He suggested "the influence of energy is seen to be ubiquitous, with economic, political, social, psychological, and ethical consequences intermeshed" (p.23). The reference to "types of energy" distinguish Cottrell's work from that of Scott (1933) and the Technocrats who failed to distinguish the different qualities of different forms of energy. Cottrell's approach to the dynamics of human society and systems was supposed to find "many welcome users among those of like interests in the various social fields" (Mayer, 1955, p. iii). Thirty-eight years later, Cronon was still calling for a unification of historical and ecological study stating "the time now seems ripe for all these different disciplines—ecology, history, geography, anthropology, and others—to acknowledge that their intellectual journeys have been carrying them toward a common path" (Cronon, 1993, p. ix). These calls and expectations seem to demand the application of general systems theory.

Emergy evaluation is not simply the study of energy flows. Emergy is instead a metric chosen to measure flows and storages of energy, material, labor, and information. Energy can be the basis of the emergy metric because all energy, material, labor, and information, in short everything that is recognizable, contains some available energy. This important characteristic distinguishes emergy evaluation from the "calorific obsessions" of ecologic and anthropologic methods that often failed to distinguish among different qualities of energy.

Emergy theory uses general systems principles (or principles that are common to both ecosystems and human systems) in a manner which may be comparable to that in which social

Darwinism applies biological principles and concepts to human cultural processes. However, because of emergy theory's basis in the maximum-empower principle, emergy theory and social Darwinism are significantly different. Though it contains similar aspects, emergy theory differs from Scott's (1933) Technocracy movement because emergy uses transformities to place different qualities of energy, material labor, and information on a common basis while still recognizing they are different. Approaching the problem from outside ecology, Soma (1993) seems to have tried to develop a technique similar to emergy using an "energiomaterial" method that accounts for different qualities of energies.

A basic precept of general systems theory is that parts of a larger whole often behave differently when isolated from their environment (or system) than they do when not isolated (Von Bertalanffy, 1968). This precept requires that both the direct and indirect inputs to a process must be included in emergy evaluations, and that a scale larger than the system itself be analyzed when evaluating inputs to the system. The whole planet is chosen when calculating the solar transformities of basic driving forces like wind, rain, tide, and geologic products.

Some general systems concepts such as system organization for maximum-empower, have been criticized as being teleological (Hagen, 1988), viewing natural phenomena as the product of design of purpose rather than random chance. Design or purpose is a valid concept in general systems analysis, however. Events at one scale are often determined by actions at a larger scale. This control and responses to it may appear as purpose or design if viewed from the smaller scale, when in fact they are simply the processes of self-organization. Short-time, small-space details and events on the smaller scale are not controlled by the larger scale system.

It follows that emergy evaluations made on the time and space scales of the United States and the Civil War may be related to larger scale events but should not be expected to be related to small-scale variations in individual human behaviors. An evaluation at the smaller scale appropriate to the behaviors would be required. The maximum-empower principle suggests that the thermodynamic constraints of previous energy flows may drive the eventual success or failure of society's chosen management strategies, though time scales of these eventual successes or failures may be very long (macro rather than micro). The emphasis of emergy is not on constraining system designs, but rather on constraining the fitness of these systems designs; simply put, the natural selection of systems.

This driven concept of systems ecology may be traced to Lotka through Hutchinson (1948) who described "circular causal systems" that had physical and biological characteristics, including feedback loops, that allowed both self-correction and oscillations. According to Hutchinson, these self-corrections and oscillations could drive some elements of the system to extinction. These contentions provided a basis for combining divergent thoughts within ecology (Taylor, 1988) and according to general systems theory should provide a basis for combining divergent thoughts within the study of human history, society, and systems. Darwin described the analogous situation for species as "How fleeting are the wishes and efforts of man! how short his time! and consequently how poor will his products be, compared with those accumulated by nature during geologic periods" (1979, p.133).

Emergy and Historical Theory

The root of emergy as an historical theory is probably best traced back to Carnot's 1824 essay on the motive power of heat. This essay was made famous by Thompson (Lord Kelvin), Clausius, and Helmholz (Adams, 1928) who developed from it the second law of thermodynamics. Thompson stated the second law as:

> 1.) there is at present in the material world a universal tendency towards the dissipation of mechanical energy,
> 2.) any restoration of mechanical energy without more than an equivalent dissipation, is impossible in inanimate material processes, and is probably never effected by means of organized matter, either endowed with vegetable life or subjected to the will of an animated creature. Thompson (1852, p. 514)

Henry Adams (1928) used this development of the second law to begin his 1909 work *The Tendency of History*, a discussion of a "physical theory of history." Adams also cited a passage from Tyndall's 1862 lecture "Heat as a Mode of Motion" which bears striking similarity to the concepts behind emergy. Tyndall stated, "look at the integrated energies of our world,—the stored power of our coal fields;—our winds and rivers;—our fleets, armies and guns! What are they? They are all generated by a portion of the sun's energy" (Adams, 1928, p.6).

Adams specifically claimed "the [University's] department of history needs to concert with the departments of biology, sociology and psychology some common formula or figure to serve their students as a working model for the study of the vital energies; and this figure must be brought into accord with the figures or formulas used by the departments of physics and mechanics" (Adams, 1928, p. 127). Around this same time, Ostwald (1907) was emphasizing that the laws of energetics must serve as the foundation of the natural sciences (not without some dissent (Carus, 1907), however).

Thomas (1925) claimed that, with the exception of climate, no environmental factor in social development had received as much attention from ancient and modern authors as had natural resources. It is not surprising then that Howard W. Odum would state in his work *Understanding Society*,

> one of the best approaches to understanding a given society is an invemory of its resources and of their development and utilization by the people of that society. Such and inventory implies systematic analysis based upon two main inquiries. The first has to do with the nature and range of resources, and the second with their conservation, development , and use. Odum (1947, pp. 60-61).

In 1927, Odum described the importance of environmental resources in the study of social problems (Odum, 1927), and by his 1947 work, he identified five general types of resources (natural, technological, capital, human, and institutional or cultural) that are in many ways quite similar to the flows and storages measured in emergy evaluations.

Also during the 1940s, White published a paper that touched on the basic concepts behind emergy. In his paper on "Energy and the evolution of culture" White claimed "everything in the universe may be described in terms of energy" (White, 1943, p. 335). He traced the intellectual origins of his arguments back to the nineteenth-century Evolutionist school of anthropology typified by Lewis Morgan (1877) and E.B. Tylor (1883; 1916). Some of these energy concepts were incorporated into ecological anthropology. The "new" ecological anthropology arising after

1970 has tended to concentrate on small-scale systems (Halperin, 1989). Ecology has followed a similar trend towards the small-scale (McIntosh, 1985; Hagen, 1988).

The *Annales* school of historical thought or French social history has many characteristics that make it an important consideration when applying emergy techniques to human economies and societies. The most apparent characteristic that relates the school to emergy is its tendency or desire for the "grand synthesis" (Forster, 1978; North, 1978). The school had its origins in France with the school's first adherents' criticism of the detailed history of political events they termed "*histoire événementielle*" or history of events (Prost, 1992). Two of the first adherents and leaders of what Burke (1990) calls the "French Historical Revolution", were Lucien Febvre and Marc Bloch. In the first issue of the journal from which the school was to take its name, *Annales d'histoire economique et social*, editors Bloch and Febvre (1929) stated that they planned the journal regretting the barriers between historians and workers in other disciplines and emphasized the need for intellectual exchange (Burke, 1990).

Wallerstein (1978, p.6) more specifically interprets Bloch and Febvre as complaining "of the 'evils engendered by a divorce that has become traditional,' both the divorce between historians and those who study contemporary economies and societies, and the divorce within 'cloistered' groups of specialists." Bloch and Febvre also stated that they intended to stand against these divisions "not by means of methodological articles or theoretical discussions. But by example and by deed" (Wallerstein, 1978, p.6). There is striking similarity between Bloch and Febvre's stand for integrated history and Von Bertalanffy's (1955; 1968) call for the development of unified theories of science running vertically through the individual sciences described above.

Another leader of the *Annales* school, Fernand Braudel, cautioned that "we must beware of that history which still simmers with the passions of the contemporaries who felt it, [and] lived it" (Braudel, 1980a, p. 4). He also stated that "resounding events often take place in an instant, and are but manifestations of that larger destiny by which alone they can be explained" (Braudel, 1980a, p. 4). Braudel's contentions parallel those of H.T. Odum regarding the need to observe mechanisms at scales larger than the system under analysis and to include environmental factors that are independent of human choice and preference when considering ecological and environmental questions (Odum, 1973; 1983; 1994).

Braudel's two works, *The Structures of Everyday Life* (Braudel, 1981) and *The Wheels of Commerce* (Braudel, 1982) also discussed many of the concepts covered by Odum (1973; 1983; 1994). These included cycles of order and disorder, social hierarchies, urban hierarchies, energy sources, balances of trade, and stability verses change. Braudel's *The Mediterranean and Mediterranean World in the Age of Philip II* (Braudel, 1980b) was criticized as having or being based upon an historical determinism that was not responsive to human control (Burke, 1990). Odum distinctly argues that this sort of determinism is a valid factor in human events, and the deterministic concept is an important component of many of Odum's arguments. Further similarities between Braudel and Odum are emphasized by the fact Braudel's works contain several discussions that would require very little manipulation to be readily and meaningfully evaluated using emergy.

Le Roy Ladurie, another important *Annales* historian, also emphasized the importance of long-term environmental processes. He went so far as to entitle a discussion of climate and weather as a potential field for historical study "History without People" (Le Roy Ladurie, 1979). In the United States, the field of ecology was discussing its potential applications to human history at least as early as a 1948 symposium at an Ecological Society of America meeting (Malin, 1950). Lloyd (1991) cited the work of Hoskins (1955; 1976), Price (1963), McNeill (1977; 1980; 1983), and Crosby (1986) as being among the closest English-language equivalents to *Annales* structuralism, while citing their lack of a formalized methodology.

The emergy approach, or its predecessor the energy systems approach, have been applied to history in several studies. Odum (1971) briefly discussed several historical questions. Odum and Brown (1976) and Odum and Brown (1977) analyzed the historical energy use of Florida and Sipe (1978) expanded on this with particular reference to the displacement of systems with settlement and development. Boyles (1975) examined the use of embodied energy (a predecessor of emergy) to develop a historical calibration for modern accounting calculations. Odum (1986b) presented an analysis of nineteenth-century Ireland and the impact of its potato famine. Huang and Odum (1991) analyzed the evolution of the island nation of Taiwan from 1960 to 1987. Sundberg completed some of the most extensive historical evaluations. These studies used both the quantitative and conceptual techniques of emergy and energy systems analysis to analyze Sweden and its seventeenth-century Baltic empire (Sundberg, 1991; 1992; Sundberg et al., 1991; 1994a; 1994b).

The United States in 1860 and the Civil War

Mid-nineteenth Century U.S.A.

The human system of the mid-nineteenth century United States was fairly simple in comparison to the modern U.S. (Figure 1-1). By 1860 the U.S. had already undergone the initial stages of the industrial revolution and had experienced large increases in agricultural and manufacturing production as well as in population (Gallman, 1980; Uselding, 1980). By 1860 20% of the population lived in an urban environment. This was up from 7% in 1820 and represents the fastest rate of urbanization in U.S. history (McPherson, 1992). The country as a whole was still dominated by agriculture and resource extraction. In terms of non-renewable resource use, the United States production of non-ferrous mineral ores (copper, lead, zinc, gold, and silver) increased through the nineteenth century from a small fraction of the world total to over a third as a result of the establishment of mining in the western states and territories (Herfindahl, 1966). Transportation, particularly railroads, expanded rapidly in the years preceding the Civil War, though there was only a limited railroad connection between the North and South (Taylor, 1952; Fishlow, 1964; 1965). Manufacturing in the Northeast and the Old Northwest was fairly advanced (Uselding, 1980), though it had yet to truly undergo the explosive, fossil fuel driven growth it would experience towards the end of the century. These industries were powered primarily by wood fuel and water-power until the 1880s (Pratt, 1980). Manufacturing industries

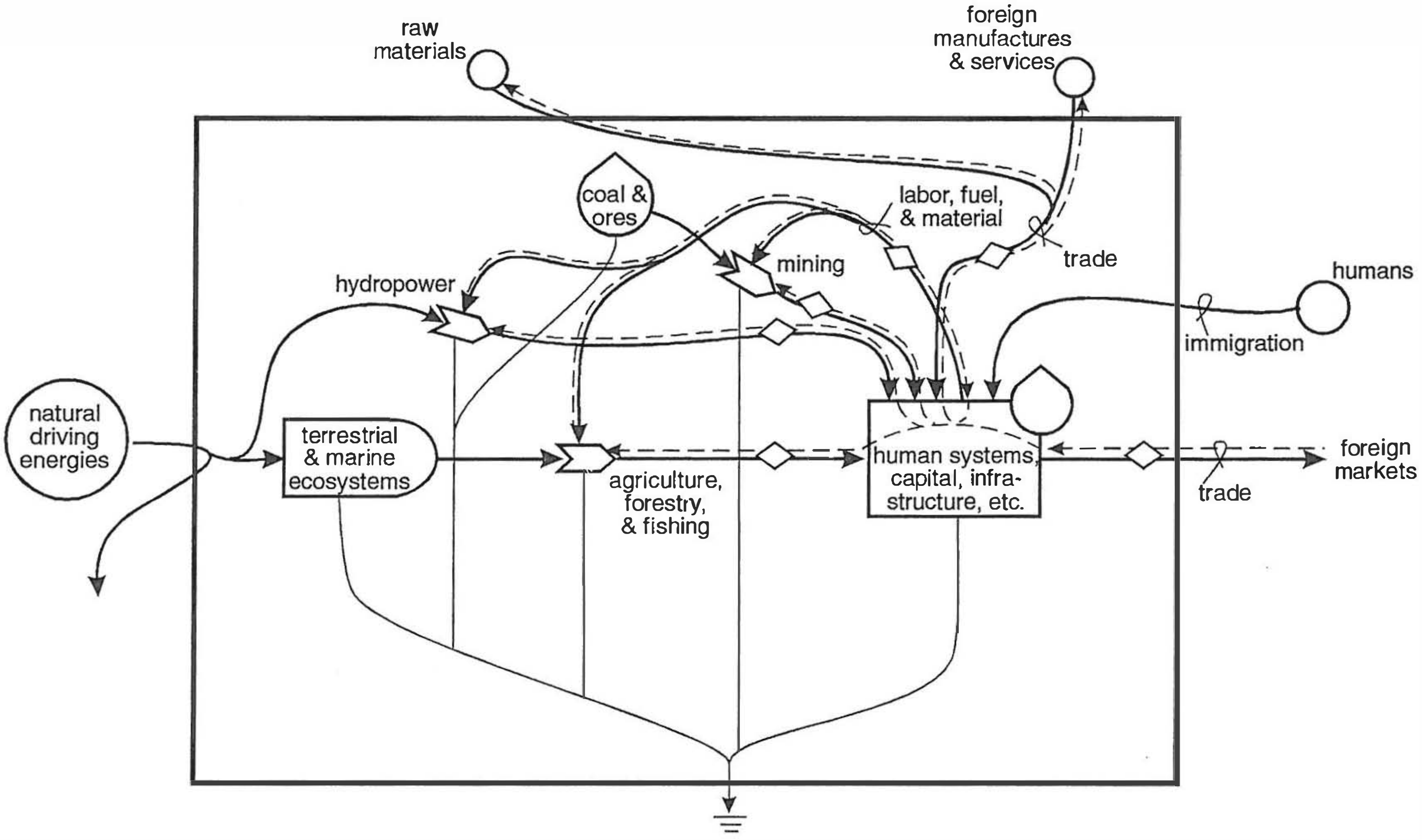


Figure 1-1. An energy circuit diagram of an aggregated model of the United States in 1860.

in the South were few and widely scattered. McPherson (1992) among others, describes the ante-bellum Southern economy as "colonial." Much of the economy was devoted to the export of agricultural and forestry products, there was little manufacturing, and many of the export agents were Northerners working for Northern firms.

The majority of the United States' population on the eve of the Civil War was east of the Mississippi River, and the country had large areas of unsettled lands on the western plains (Figure 1-2). Yet, a majority of the population was still relatively isolated because slow transportation limited communication and the movement of people. As evidence of this relative isolation, the rural recruits to the Civil War armies would suffer much higher deaths from disease (particularly childhood diseases like measles) than their urban comrades because the rural men had not been exposed to many of the common diseases.

Background of the Civil War

The first organized armed conflict that can be seen as part of the Civil War took place between paramilitary groups in the conflicts of "bleeding Kansas." From 1854 until the War, a struggle occurred in the Kansas Territory and a debate in Washington, D.C. concerning whether Kansas would be admitted to the United States as a free or slave state. McPherson (1992; 1993) claims that few people would have disagreed with Lincoln and Stephen's (the President of the United States and Vice President of the Confederate States, respectively) statements that slavery was the cause of the Civil War. In the many years since the War, several schools of thought on the War's causes have arisen. A discussion of the historiography (the techniques and methods historical research) of the Civil War causes is warranted here because certain data and interpretations used in this study were produced under the influence of these schools.

While slavery as the primary factor behind the War remained the dominant interpretation until at least the early 1900s, within the first few years after the war the idea arose that the southern states had gone to war to protect state sovereignty (states' rights). The state's rights

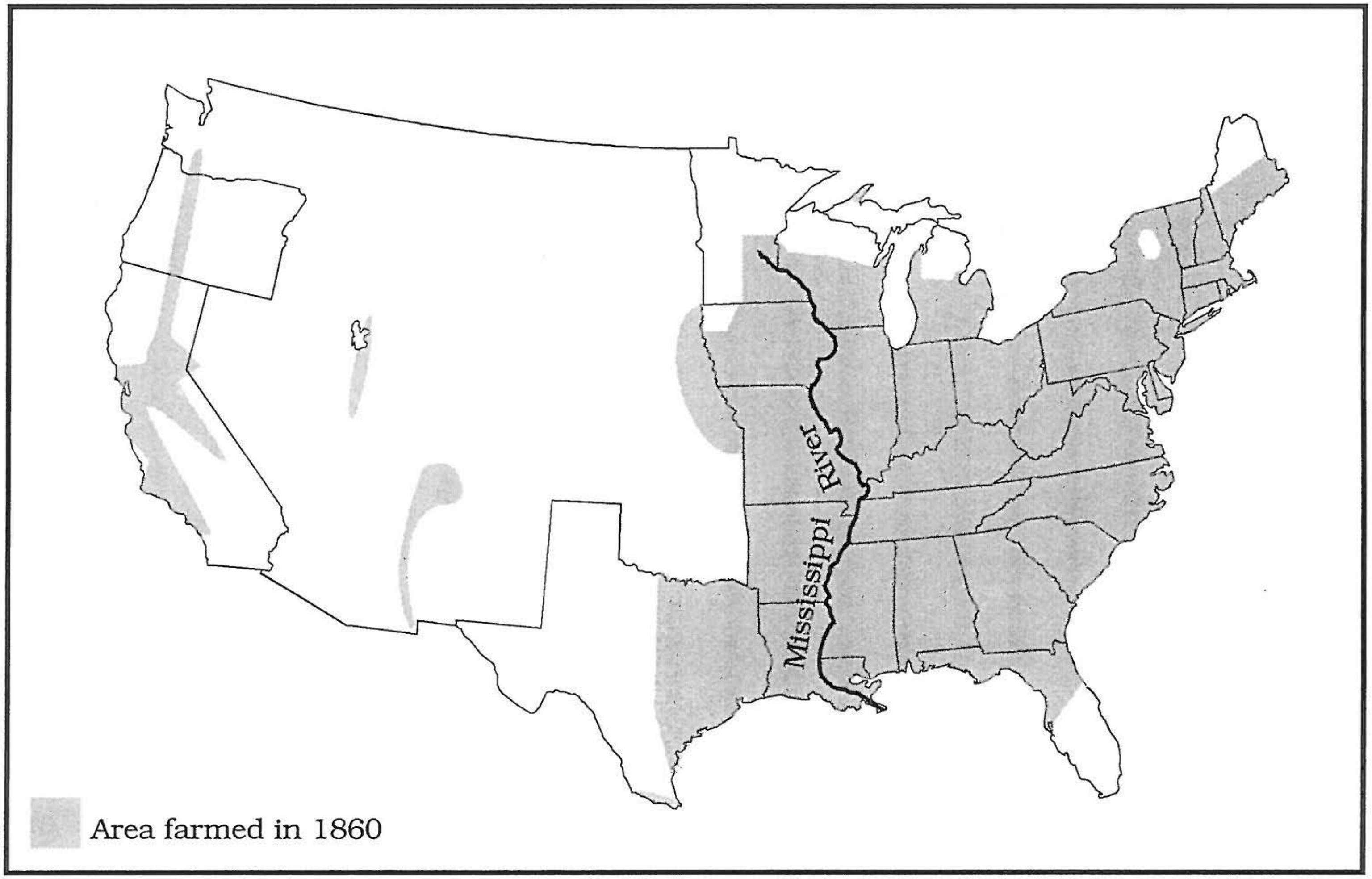


Figure 1-2. United States land area farmed in 1860 (from USCO (1864) data).

argument existed before the War but seems to have gained particular prominence after the War in attempts to salvage honor in defeat when slavery no longer seemed an appropriate cause for secession (Beringer et al., 1986; McPherson, 1993). There were approximately 4 million slaves valued at 3 billion current dollars in the South in 1860 (USCO, 1864). The expansion of slavery into the new Western territories opening to settlement as opposed to the existence of slavery seems to have been a driving force behind the North-South conflict. Slavery's supporters feared the admission of free states would alter the balance between free and slave states in the U.S. Senate and endanger the existence of the institution of slavery. Opponents of slavery feared at least one of three things: 1.) that the economic power and capital of plantation owners (or the "Slavocracy") would deny western lands to northern yeoman farmers; 2.) that the institution of chattel slave labor degraded laboring classes in general and inhibited social mobility; or 3.) that slavery was morally wrong (Stampp, 1956; Genovese, 1965; Foner, 1970; Jordan, 1974; McPherson, 1992).

Both slavery and sovereignty became suspect from the 1920s to the 1940s as a the "Progressive school" of historians came to dominate the American scene. Rooted in materialism and doubting whether a people would go to war over principles alone, this school emphasized conflicts between social groups and economic interests. They interpreted the War as the end result of a long-running conflict between plantation agriculture and industrializing capitalism to the extent that some considered it only an accident that plantation agriculture was located mainly in the South and industry mainly in the North (Beard, 1927; McPherson, 1993). They emphasized the tariff, federal support of internal improvements, and the distribution of public lands as the real issues dividing the country in 1860. Though the concept or at least term "wage slave" to describe northern industry laborers was developed before the war (Kettell, 1860), some progressive historians reiterated the similarities between Southern black slaves (in chattel bondage) and exploited white, urban labors of the North (McPherson, 1993). During this period, some of the extreme work of the "Lost Cause" historians saw the war as a struggle which ended in "the triumph of the acquisitive, power-hungry robber barons over the highest form of civilization America had ever known—the Old South" (McPherson, 1993, p. 318). McPherson's (1993) historiography of the Civil War cites the dominance of a revisionist school during the 1940s. This school minimized the regional and economic differences of the ante-bellum United States and placed blame for the cause of the war on extremists in the North and the South. Since the 1950s, historiography of the War has come back to seeing slavery as the root cause.

Slavery existed in the United States from the earliest days of the English and Dutch colonies, with imported African slaves and their descendants supplanting other forms of contact labor like indentured servitude. Among the first recorded conflicts over slavery in what would become the United States, was the refusal of an outpost commander for the Dutch colony of New Netherlands (New York) to surrender to the English a slave who had escaped from the New England colonies (Page, 1892; Provost 1894). An aggregated model of the United States slavery system emphasizing the particular components and processes is diagrammed in Figure 1-3.

By 1860, only about 10% of slaves worked in industry or mining, and almost half the slave-owners owned less than five slaves. However, the typical slave of 1860 was held on a large plantation (a farming operation with 20 or more slaves) (Fogel and Engerman, 1974; Fogel et al., 1989). Less than 12% of all slave owners owned more than 20 slaves and less than a quarter of the South's white, adult males owned a slave (Fogel and Engerman, 1974; Fogel et al., 1989). Thus, the soldier in the Southern Army did not own a slave or go to war to keep his slaves. The reasons they went to war are still debated (Genovese, 1965; 1975; McCardell, 1979; McPherson, 1993), but the concept of slavery as integral to the Southern way of life seems to have been a driving force (McPherson, 1992). The profitability of slavery and its effect on Southern economic development has been widely debated. Some recent evidence suggests that slavery may not have been as economically doomed in 1860 as had been suggested in previous debates (Fogel et al., 1989).

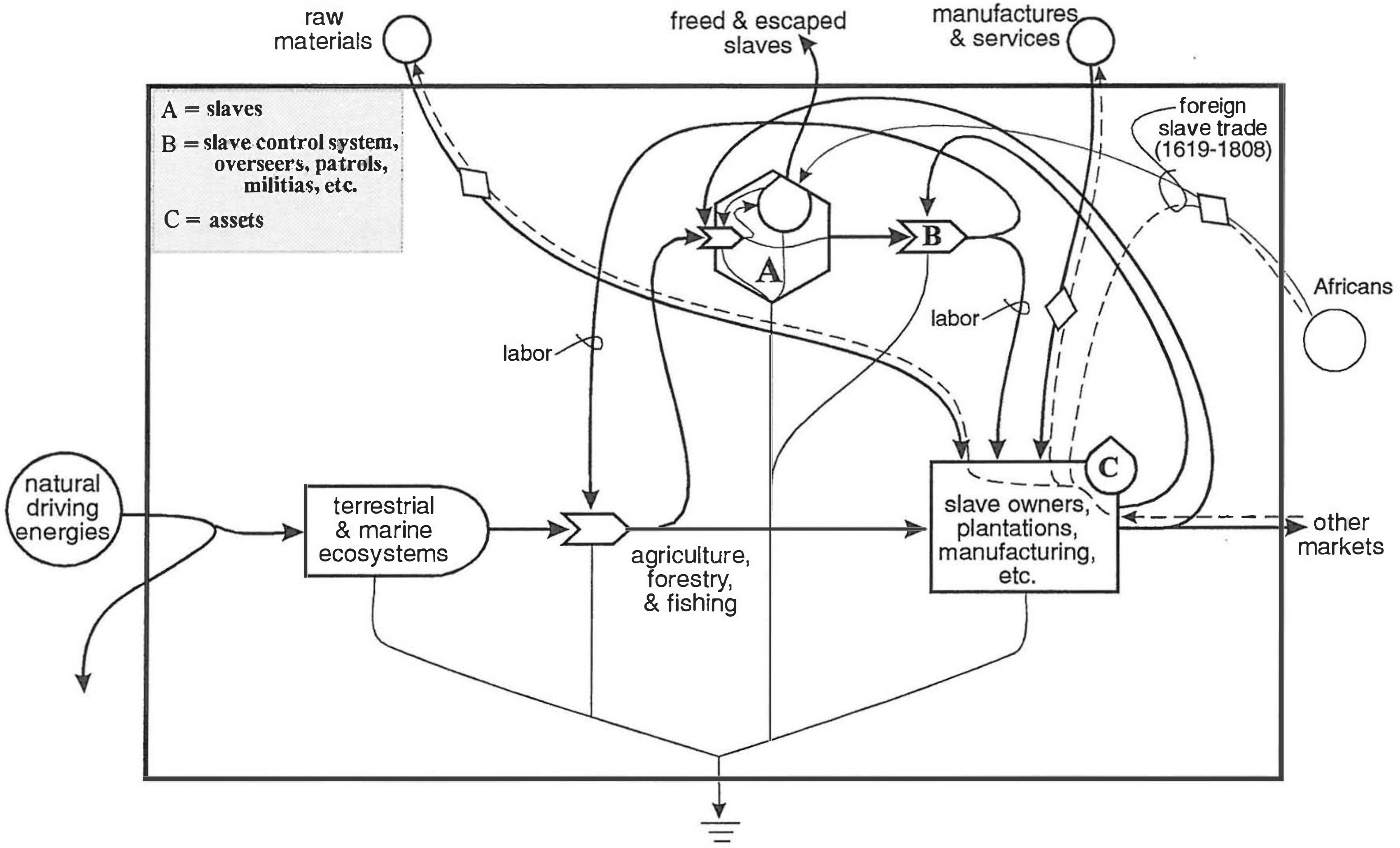


Figure 1-3. A model of the United States slavery system.

The War, 1861-1865

The Civil War was precipitated by the South's reaction to the election of Abraham Lincoln, who favored preventing the expansion or extension of slavery, as President in November 1860. South Carolina seceded from the Union 20 December 1860 and was followed by ten more states ending with Tennessee on 8 June 1861. These seceding states formed the Confederate States of America (C.S.A.) with its capital in Richmond, Virginia. Of the 22 states that remained in the Union or the Federal government, at least four slave holding border states (Missouri, Kentucky, Maryland, and Delaware (Figure 1-4)) sent almost 90,000 troops to the Confederacy and about 210,000 to the Union. Approximately 150,000 former slaves from Southern states would eventually fight for the Union (McPherson, 1992). An aggregated model of the Civil War showing the basic systems supporting military operations is diagrammed in Figure 1-5.

The majority of the significant military operations of the Civil War on land took place east of the Mississippi. Significant operations may be grouped into: 1.) land actions of the eastern armies; 2.) land and river actions of the western armies (still generally east of the Mississippi); 3.) the Union blockade and capture of Confederate ports and Confederate efforts to run or break the blockade; and 4.) Confederate commerce raiding against Union ocean-going, merchant ships and Union efforts to counter it. Having maintained control of the pre-war navy, the Union began the war with a large advantage in naval power and maintained this advantage through the war. The pre-war army had been small and many of its officers resigned to join the Confederacy so both the Union and Confederacy were forced to recruit armies.

Military action in 1861 and 1862 was dominated by conflicts in the area between Washington, D.C. and Richmond and in Tennessee and Louisiana (Figure 1-6). The Union captured of key areas of Louisiana and Tennessee during 1862. The Confederate army in Virginia eventually came to be the "Army of Northern Virginia" commanded by General Robert E. Lee. The Union capture of New Orleans was followed by Union attempts to capture Vicksburg, Mississippi from the north in order to sever the eastern Confederacy from the trans-Mississippi Confederacy (Texas, Arkansas, and western Louisiana), divide the Confederacy in two, and

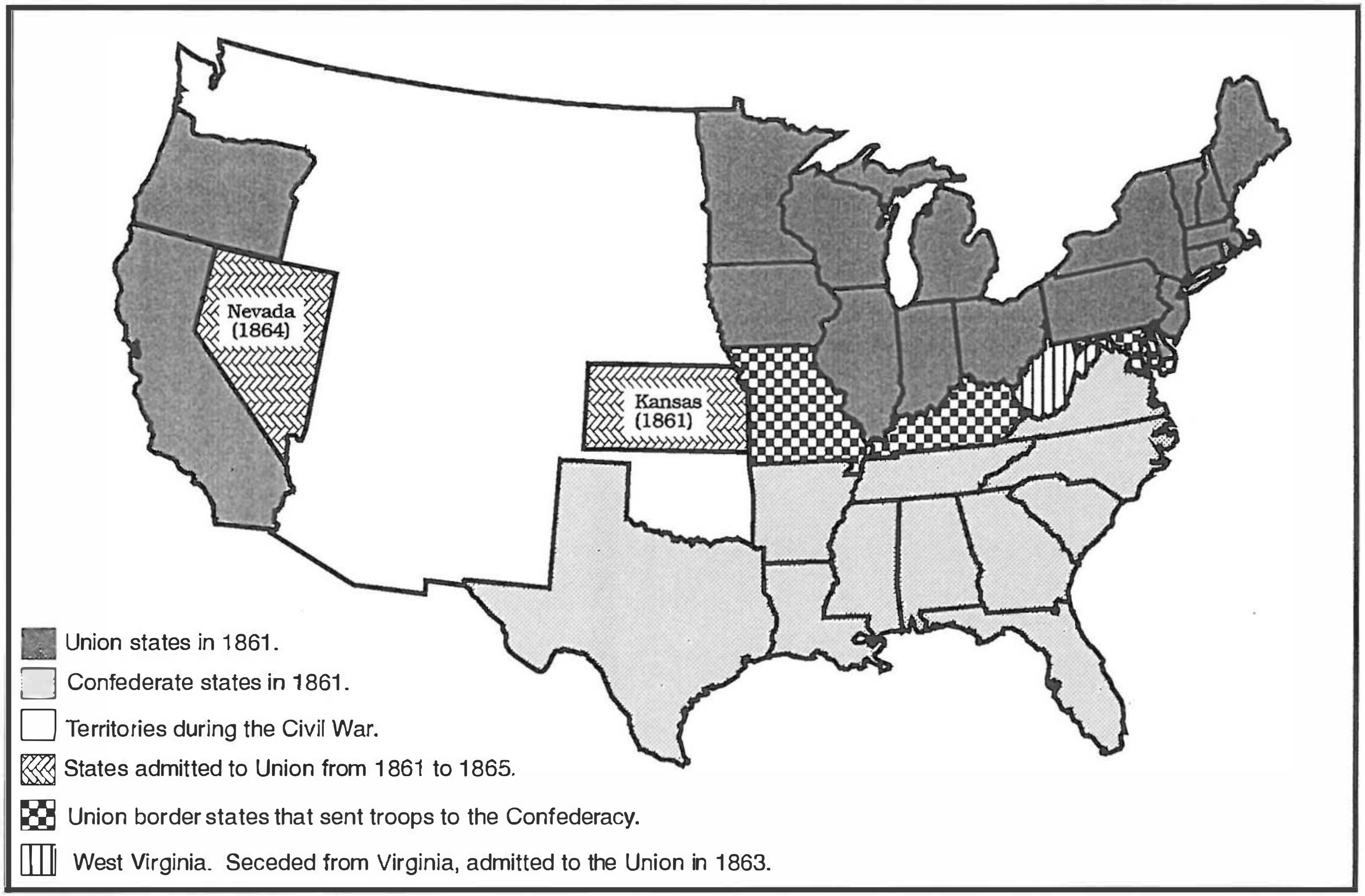


Figure 1-4. Union and Confederate states during the United States Civil War.

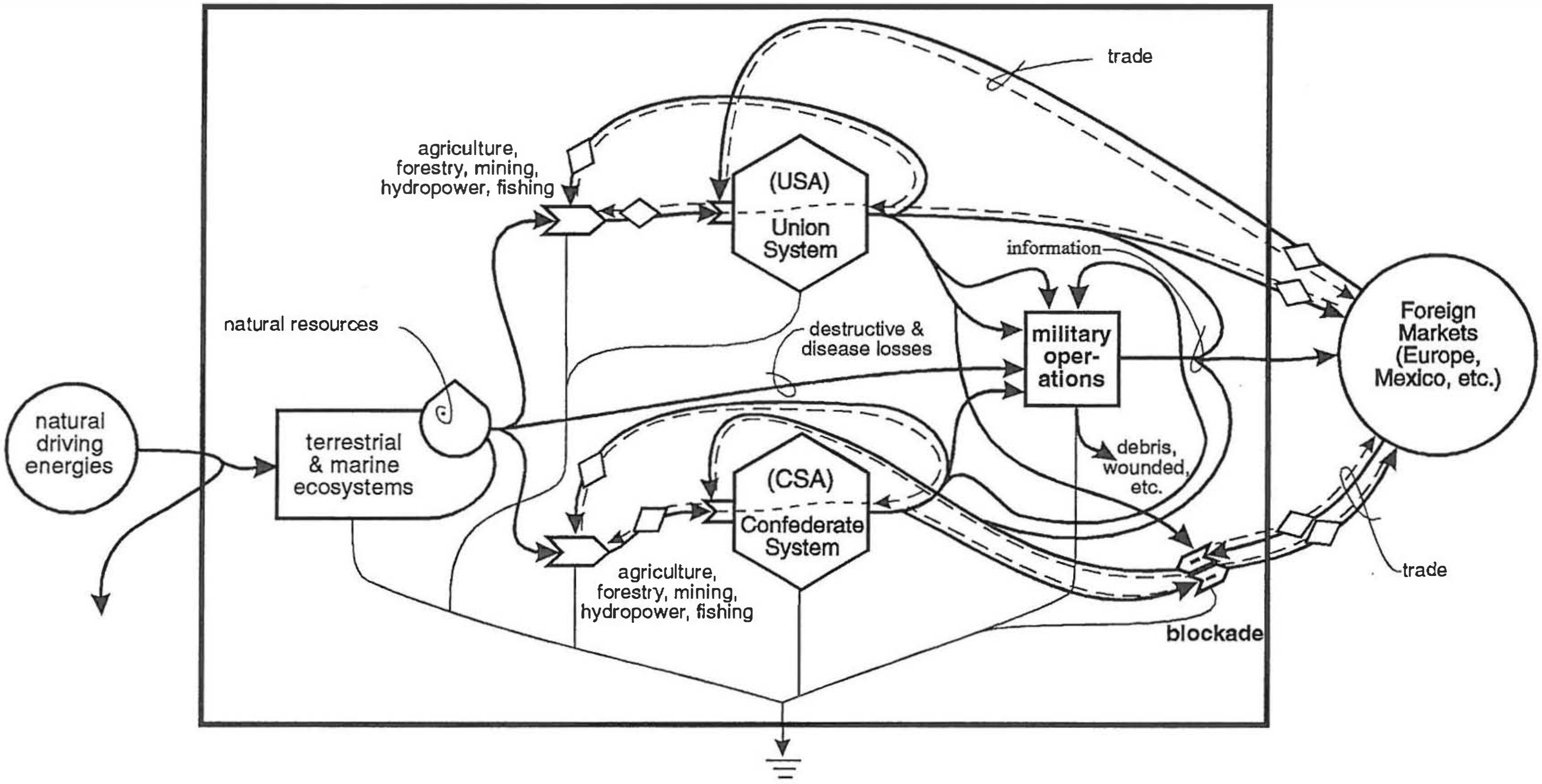


Figure 1-5. An aggregated model of the United States Civil War, 1861-1865.

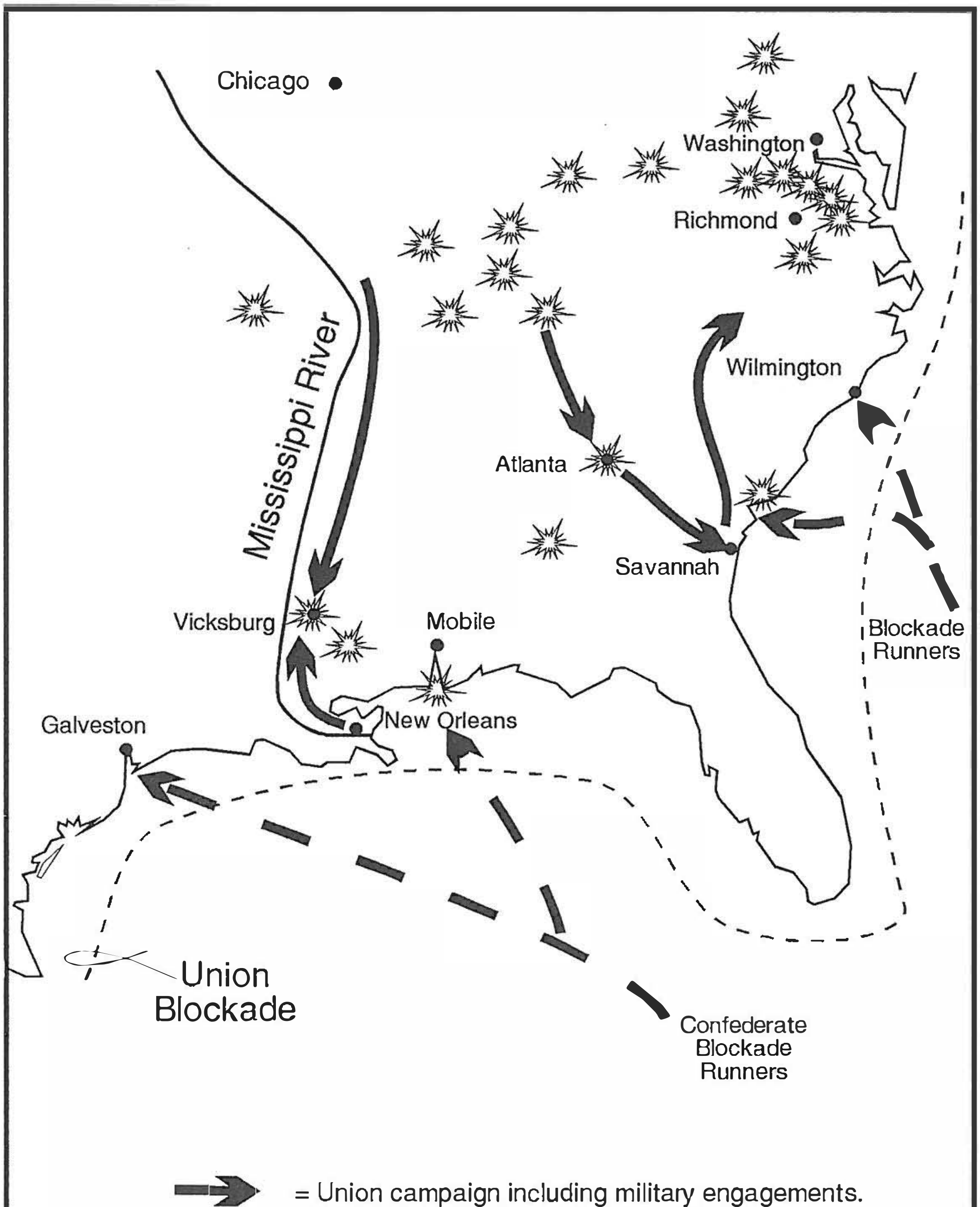


Figure 1-6. Some of the major engagements and operations of the United States Civil War.

prevent the flow of food and war materiel from Texas and Arkansas to the East. The Union repulse of Lee's attempted invasion of Maryland at Antietem Creek (Sharpsburg) in September 1862 was a singular Union victory among Lee's many defeats of the Union forces in the East. This victory was followed by Lincoln's Emancipation Proclamation, a Union decree freeing slaves in all rebelling states. Several more Confederate victories occurred in the East before July 1863 when the Union turned back a Confederate invasion of the Pennsylvania at Gettysburg, and Vicksburg fell to the Union forces under General Ulysses S. Grant after a siege. At the same time, Confederate armies were being driven south out of Tennessee (Figure 1-6). There was significant opposition to the War in the North during 1862 and 1863 including large riots against the draft.

The year 1863 ended with a Union breakout at Missionary Ridge outside Chattanooga that forced the Confederates to begin a fighting retreat towards Atlanta. Union forces in the East, now effectively under the command of Grant, attacked the Confederates in the spring of 1864 and began an almost continuous series of battles that ended with the Union laying siege to the Confederates around Petersburg, Virginia in June. Atlanta was captured by the Union general William Sherman in September. Sherman left Atlanta in October and moved towards Savannah in his "March to the Sea," destroying much of central Georgia's agricultural and industrial capacity along the way (Figure 1-6). The forts at the entrance to Mobile Bay, Alabama, were captured in the summer of 1864 closing another port through which the Confederacy had brought supplies to sustain its armies.

Sherman attacked from Savannah up into the Carolinas cutting off Wilmington, North Carolina, and Charleston, South Carolina, in February 1865, effectively closing the Confederacy's last major blockade running port. The Confederate armies in Virginia had been almost entirely dependent on supplies of food, clothing, and ammunition run through the blockade in the months preceding the loss of Wilmington (Wise, 1988). The Confederates evacuated Richmond and Petersburg in the beginning of April and Lee, surrounded by Union forces, surrendered to Grant on 9 April 1865. Other Confederate forces surrendered over the next few months. The last important Confederate force, the commerce raider *Shenandoah*, surrendered in November 1865 though the

War in Texas was not officially over until August 1866. The Thirteenth Amendment to the U.S. Constitution, abolishing slavery in the U.S., went into effect in December 1865.

Plan of this Study

This study used the United States Civil War to examine the application of emergy theory to the study of human history. Because it analyzed how well emergy predicts human welfare and success, this study also served as a test of the application of emergy theory to environmental policy involving humans. A basic hypothesis to be tested is that the fitness and success of processes and systems of human society can be measured and predicted with emergy. Emergy evaluations were conducted for relevant systems at different scales of time and space in order to observe the scales and manners in which the maximum empower principle manifests itself in the history of human society. These evaluations included: sub system studies to determine the transformity values of several important products in the nineteenth century; the entire U.S. ecologic-economic system in 1850, 1860, and 1870 (Figure 1-1); Great Britain in 1860; the U.S. system of slavery in 1860 (Figure 1-3); the systems of the Confederate and Union states in 1860 and over the course of the war; and the Civil War in its entirety (Figure 1-5).

The evaluations were interrelated and dependent upon one another for transformities, emergy-money ratios, annual empowers per capita, and other emergy conversions (Figure 1-7). The evaluations were used to compare the United States in 1850, 1860, 1870, and 1983, Great Britain in 1860, and the Confederate and Union states in 1860. The evaluations compared transformities in 1860 with those in other time periods, examined the trade, immigration, and natural resource extraction patterns of the United States in 1860, and examined general systems properties of war.

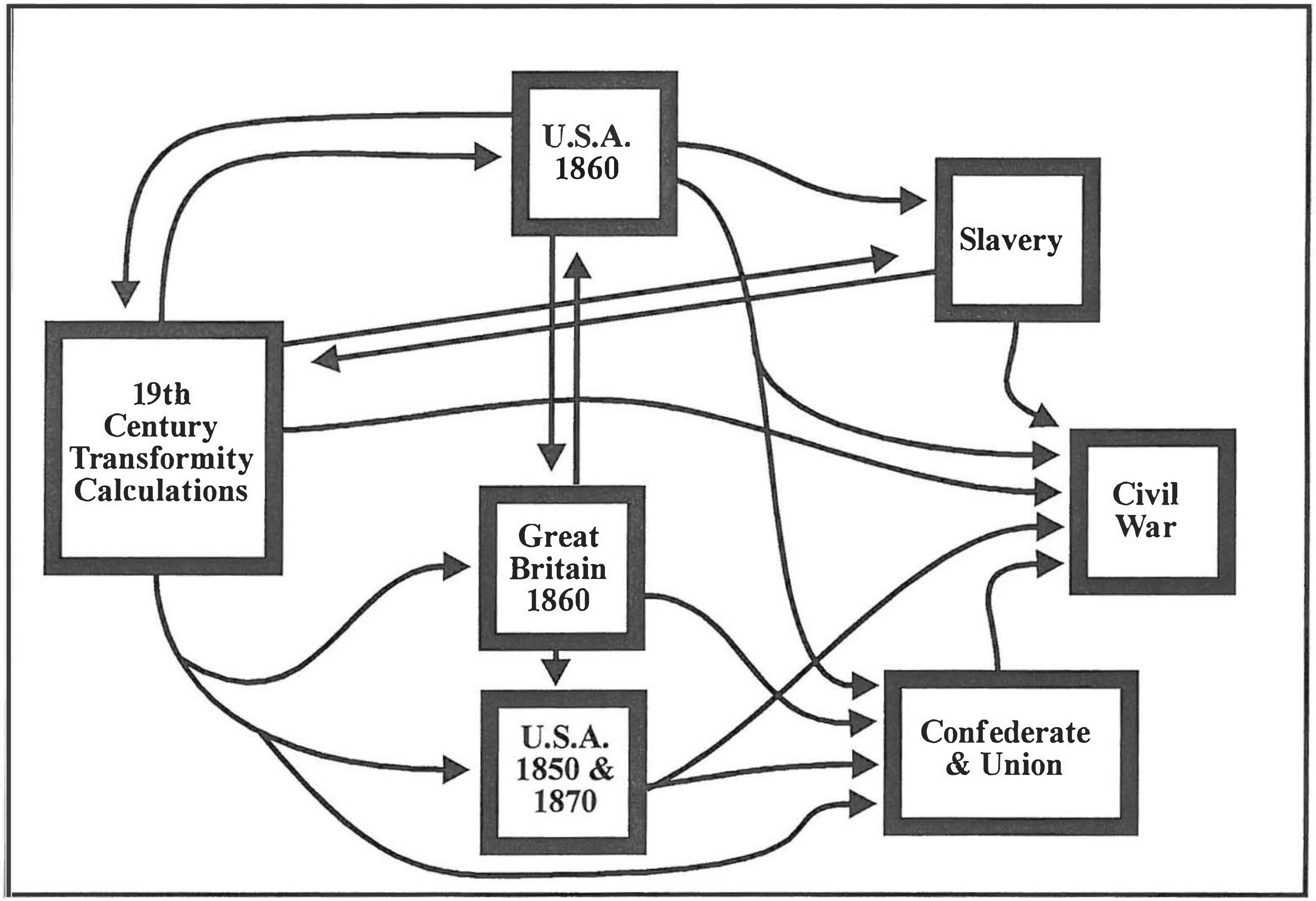


Figure 1-7. The relationships between the evaluations of this study. The arrows represent transfers of information in the evaluation processes.

CHAPTER 2
METHODS

General Emergy Evaluation Methods

The emergy evaluation techniques for systems and processes outlined by Odum et al. (1977), Odum et al. (1987b) Odum, (1987a; 1989; 1994) and used by Odum (1987b), Odum et al. (1987b), Brown et al. (1988, 1991; 1993), Philomena (1990), Odum and Arding (1991); and Huang and Odum (1991) begin with the construction of a conceptual model of the energy flows into, and exports from the system of interest, as well as changes in energy storages within that system. These energy estimates are then converted to emergy using transformities calculated from these or analogous models. Transformities are calculated by analyzing the historical energy flows leading to a process in order to determine the total energy of one form directly and indirectly required for production of the form of energy generated by the process of interest. The emergy values may then be added to generate totals and indices such as the annual emergy flux into (empower) of the system, the empower per capita of the system, and the net emergy yield (the emergy of an input energy flow divided by the emergy necessary to process the flow) of the process or system. These statistics are used to evaluate and characterize the system or processes.

Energy Systems Diagramming

The first step in an emergy evaluation is often energy systems diagramming with the energy circuit language (Odum, 1971; 1983) to create a conceptual model of the system or process of interest. This model serves to help detail both the processes within the system of interest and the effect of the next larger system on the system or process of interest (Odum, 1994). An initial, detailed diagram is often simplified by aggregation to highlight the flows used in the emergy evaluation. The final model diagram usually includes pathways contributing energy, materials, or labor from outside the system; major, long-term storages within the system; and pathways of particular interest because of their importance to the system or evaluation (particularly pathways subject to change under the evaluation). Processes (transformations of energy) that are important to the evaluation are also included in this final diagram.

Splits and Coproducts

The emergy technique differentiates between split flows and coproduct flows where many embodied energy analysis techniques do not (Odum, 1994). Examples of split flows from this study are two flows of salmon biomass production, one that is consumed by bald eagles and a second that is harvested by humans. An example of coproduct flows are fiber and seeds in a cotton boll. From the initial plant product, the boll, seed is removed by ginning and fiber is converted into thread and yarn. Split flows are defined as flows partitioned from the same original source flow but remain in the form of the initial source flow. Coproduct flows, by comparison, are flows of different forms produced by the same process. A byproduct flow cannot be produced independently of its associated by-product flows by the given process. The emergy of the original flow is partitioned among split flows, but the full value emergy driving the production process is assigned to each of the coproduct flows. If coproduct flows (two pathways that derive their emergies from the same source) re-combine, double counting is avoided by assuring only the original source emergy value is used.

Emergy Evaluation Table

The emergy evaluation tables most commonly used in this study consisted of five columns. An example of the table format is detailed in Table 2-1. The first column in each row is a term designated for the flow or storage evaluated in that row. This term is used in a note following the table and as a label in the diagram of the system model. The second column contains a short

Table 2-1. Format of the emergy evaluation tables used in this study.

Table Column:

1	2	3	4	5
Term	**Item**	**Raw Units (J, $, g, etc.) /time**	**Solar Transformity or Emergy Conversion (sej/unit)**	**Solar Emergy (sej/time)**

Column Descriptions:

Column 1	The designated term for the item detailed in each row. The derivation of each term is given in table's supporting calculations.
Column 2	A description of the item detailed in each row.
Column 3	The raw units of flow for each item, usually given in joules, grams, money, persons, or labor per unit time.
Column 4	The transformity or other emergy conversion for the item. The source of the transformity or emergy conversion is given in Table 2-2 or in the supporting calculations.
Column 5	The solar emergy value of the item. The product of the raw units of flow (column 3) and the term's transformity (column 4).

description of the item evaluated in the row. The third column gives the energy, money, or mass estimate of the flow or storage. The fourth column gives the solar transformity or emergy conversion of the flow or storage. These transformities and conversions are given or referenced in Table 2-2. The fifth and final column gives the emergy value of the flow or storage calculated as the product of columns three (the raw units) and four (the transformity).

All emergy evaluations in this study were conducted using the spreadsheet QUATRO PRO FOR WINDOWS 1.00. Calculations are accurate to two significant figures, but are frequently presented with more to make the calculation procedures easier to follow. To the extent the spreadsheet would allow, full figures (without regard to significance) were carried through all calculations. All input variables were halved and doubled to determine their influences on the final results.

Calculation of Nineteenth-Century Transformities

Water-Power and Steam Engine Power

Transformities were calculated for the mechanical power produced by water wheels (and turbines) and by coal burning steam engines. The transformity for water power was calculated using data from: Gordon (1985) in an evaluation of water-power development for manufacturing in New England; the 1860, 1870, and 1880 U.S. Census of Manufacturers; and Williams' (1870) analysis of railroad equipment life spans. A model of water power production was used in which transformity was determined as the sum of the empower inputs from: 1.) flowing water; 2.) human labor embodied in depreciating machinery and material; and 3.) human labor directly input in the form of maintenance work. The source of water was assumed to be a fourth order stream and a 3.5E+04 sej/J transformity calculated by Diamond (1984; Odum et al., 1987c) was used. A 0.50 capacity factor, the fraction of potential operating time the production system is actually operating, was assumed. The calculation for depreciating machinery was based upon census data for a

Table 2-2. Transformities, emergy-money ratios, emmassities, and emergy conversions from this and other studies used in this study's emergy calculations.

Form	Value	sej/unit	Source
Ash and soda	1.5E+05	sej/J	Sundberg et al. (1994a)
Chalk	1.0E+09	sej/g	estimated from limestone from Odum (1994)
Charcoal	1.5E+05	sej/J	Sundberg et al. (1994b)
Coal	3.3E+04	sej/J	Odum (1994)
Copper ore	4.5E+09	sej/g	Sundberg et al. (1994a)
Corn, grain & cob	1.3E+05	sej/J	see Results, this study
Cotton		sej/J	see Results, this study
Cotton cloth	1.9E+06	sej/J	Odum et al. (1987b)
Earth cycle	2.9E+04	sej/J	Odum and Arding (1991)
Emergy-money ratio, Confederate states		sej/$	see Methods and Results, this study
Emergy-money ratio, Union states		sej/$	see Methods and Results, this study
Emergy-money ratio, Great Britain.		sej/£	see Methods and Results, this study
Emergy-money ratio, U.S.A.		sej/$	see Methods and Results, this study
Finfish	2.0E+06	sej/J	estimated for species from Woithe (1992)
Geopotential energy in falling water	3.5E+04	sej/J	Diamond (1984)
Gold, refined	1.1E+14	sej/g	Odum (1990)
Gold in ore	5.0E+09	sej/g	estimated from Odum (1994)
Grain		sej/J	see corn
Gunpowder		sej/g	see Results, this study
Horses & mules	7.2E+14	sej/head-y	Sundberg et al. (1994a)
Humans (individuals)		sej/person	see pertinent evaluation Results
Hydro- or water-power		sej/J	see Results, this study
Iron, pig		sej/g	see Results, this study
Iron		sej/g	see Results, this study
Iron ore (sedimentary origin)	1.0E+09	sej/g	Odum (1994)
Labor, human		sej/labor	see Methods and Results, this study
Lead, finished		sej/g	see Results, this study
Lead, pig		sej/g	see Results, this study
Lead ore		sej/g	see Methods, this study
Limestone	1.0E+09	sej/g	Odum (1994)
Livestock		sej/J	see pork transformity calculation in Results, this study
Mercury	1.0E+09	sej/g	estimated from Odum (1994)
Nickel ore	1.0E+09	sej/g	estimated from Odum (1994)
Niter earth		sej/g	see Methods, this study
Petroleum, crude	5.3E+04	sej/J	Odum et al. (1987b)
Pork		sej/J	see Results, this study
Primary production	2.7E+04	sej/J	estimated from Woithe (1992)
Rain, geopotential energy	8900	sej/J	Odum (1994)
Rain, chemical potential energy	15000	sej/J	Odum et al. (1987b)
Shellfish	8.0E+05	sej/J	estimated for species from Woithe (1992)
Silver	6.5E+12	sej/g	Sundberg et al. (1994a)
Silver ore	5.0E+10	sej/g	Sundberg et al. (1994a)
Solar energy	1.0	sej/J	by emergy definition
Steam-power		sej/J	see Results, this study
Sulfur, refined		sej/J	see Methods, this study
Sulfur ore (brimstone)		sej/J	see Methods, this study

Table 2-2 continued.

Form	Value	sej/unit	Source
Tidal energy absorbed	2.4E+04	sej/J	Odum (1994)
Topsoil		sej/J	Odum et al. (1987b)
Waves absorbed at shore	2.6E+04	sej/J	Odum (1994)
Whale oil & bone	3.6E+07	sej/J	estimated from Woithe (1992)
Wind, kinetic energy	620	sej/J	Odum (1994)
Wood and timber, standing	8000	sej/J	Doherty et al. (1993)
Wool	3.8E+06	sej/J	Odum et al. (1987b)
Zinc ore	1.0E+09	sej/g	estimated from Odum (1994)

water-power driven Georgia mine in 1870. It was assumed that 25% of the mine capital's dollar value was turbine and power transfer equipment. It was estimated that this equipment had a twenty-year life span. The 1870 U.S. emergy-money ratio was used to generate an estimate for the emergy value of human labor embodied in the equipment. A maintenance requirement of 5 minutes of labor for each hour of potential operation was assumed.

The transformity for steam engine-generated power was calculated from a model similar to that for water-power except that coal fuel replaced flowing water as an input. Estimates were generated from Sopwith's (1870) analysis of British and Spanish lead ore dressing operations and from Williams' (1870) analysis. A capacity factor of 0.75 and an operation and maintenance labor input of one labor-hour for each hour of potential operation were assumed.

Iron and Pig Iron

Finished iron and pig iron transformities were calculated for iron production process fueled by coal. These transformities were calculated from a model that grouped the production of iron into two categories of processes. The two categories were derived from Fairbairn's (1861) description of mid-nineteenth century iron production. The first group of processes included calcination, smelting, and other processes involved in the reduction of iron ore to pig iron. The second group included puddling, rolling, forging, and other processes that resulted in the refinement of pig iron to finished iron. The model assumed inputs to production of iron ore, coal and coke, limestone, and labor. The model excluded: 1.) the inputs required for transportation of materials from iron mines, coal mines, and limestone quarries to iron furnaces; 2.) fuels used in the mining processes; and 3.) material, equipment, and machinery used in the mining, reduction, and refining processes.

Lead and Lead Pig

Finished lead and lead pig transformities were calculated from the combined data of several nineteenth-century U.S. and European reverberatory furnaces that produced lead from coal and charcoal. These transformities were calculated from a model that divided lead production into processes of smelting and refining, and of finishing. The model assumed inputs to production were galena lead ore (the most abundant ore (Huntingdon and McMillian, 1897)), coal, coke, wood, charcoal, flux (iron ore and limestone), and labor (including direct and supervisory). The model excluded: 1.) the inputs required for transportation of materials from lead mines, coal mines, and limestone quarries to smelting furnaces, 2.) fuels used in the mining processes, and 3.) material, equipment, and machinery used in the processes of mining, reduction, and refining.

Gunpowder

The transformity for gunpowder was calculated for the 20% niter (KNO_3), 10% sulfur, and 15% charcoal (carbon) mixture commonly used by the U.S. military for small arms (ORUCA). The water- and steam-power, labor, and machinery and materials inputs to gunpowder manufacturing were estimated from the U.S. Census of Manufacturers' data for the U.S. munitions industry (USCO, 1874).

Emergy Evaluations of United States (1850, 1860, and 1870)

The ecologic-economic system of the United States in 1850, 1860, and 1870 was defined as the area and processes encompassed within the legal borders of the U.S. in each year and a fraction of the ocean waters overlying the adjacent continental shelf to a 300 m depth. The processes within this area were then summarized as described in the energy evaluation methods section above. Several methods were used to estimate the emergy support of or empower utilized by the human systems of the United States during the analyzed years. The actual human use of the natural driving energies of the United States system (such as sunlight, rainfall, and tide absorbed in estuaries) were the most difficult supporting emergy values to determine. The values were calculated using four techniques for estimating the renewable, annual empower support of the system (the index "R"). The first method calculated the direct and some indirect use of natural emergies as the empower of cultivated areas (improved and unimproved farm land according to Census data) and 80% of the U.S. coastline during the year of evaluation. This method was chosen to calculate renewable empower in all the national emergy evaluations, but three additional methods were used on the U.S. in 1860 to scrutinize the evaluations' sensitivities to the choice of calculation technique. The first and most conservative technique estimated the direct use of natural emergies as the sum of the emergy values of timber, agricultural, and fisheries harvests in the U.S. during the evaluation year. The second method estimated direct and indirect support as the empower of the entire U.S. coastline and all U.S. land area with a population density greater than two people per square mile. A population density of two people per square mile is the approximate mean population of the least populated states and territories at the time of the U.S. Census Office's announcement of the closing of the American frontier that spurred Turner's (1893) thesis "The Significance of the Frontier in American History." This method calculated the area of emergy support as the sum of 1.) the area of the states and territories which had populations greater than one person per square mile, and 2.) the areas of other states and territories equal to one-half square mile per capita. The third and most liberal method used the entire area within the political borders of United States to calculate renewable annual empower. These areas were 7.6E+12 m^2 in 1850 and 7.7E+12 m^2 (USDC, 1975) in 1860 and 1870 (with the addition of the Gadsen Purchase).

The solar energy input to a region (term 1 in national emergy evaluation tables) was estimated by multiplying the solar energy flux per unit area by the region's area and the fraction of solar energy not reflected (1-Albedo). The input of wind energy was estimated from Odum et al. (1987a) as the product of the atmospheric boundary layer height, the density of air, the specific heat of air, the vertical potential temperature gradient, the area of the region, and the wind vector for the region (multiplied by y/s and J/Kcal conversion factors). The energy input from the gravitational potential energy of U.S. rainfall (term 3 in national emergy evaluation tables) was calculated by assuming that all rain fell at the mean U.S. elevation and that a fraction flowed to sea level. The gravitational potential energy was calculated as the product of the volume of runoff, the average elevation of the U.S., the density of the runoff, and the gravitational constant. Evapotranspiration was assumed to account for the fraction which did not reach sea level. The chemical potential energy of rain on land and the adjacent continental shelf (term 4 in national emergy evaluation tables) was estimated as the product of: 1) the annual rainfall in the region less water lost to evapotranspiration; 2) the density of rain water; and 3) the Gibbs free energy of rain water relative to the water the surrounding oceans.

The Odum et al. (1987a) estimate of the energy absorbed along the coastline of the continental United States from waves breaking on shoreline was used for the wave energy input to the U.S. This value had been estimated by calculating the energy in 1 meter of breaking wavefront as one eighth the product of sea water density, the square of average wave height, and the square roots of the gravitational constant and the average water depth under the measured wave height. The energy in one meter of wavefront was then multiplied by the shore length exposed to wave action and converted from ergs to joules. A 0.50 coefficient for the absorption of tidal energy on the continental shelf and in the estuaries of the United States was assumed. The tidal energy absorbed in the U.S. system (term 6 in national emergy evaluation tables) was estimated as the volume of water in each tide raised to the square of the mean tidal range (to determine forces acting upon the water mass by relating the range to the gravitational constant) for the half the number of annual tides (as the range is across one tidal cycle or two tides). This product was multiplied by the density of sea water and the gravitational constant, then converted to joules. The earth cycle input to the U.S. system was also estimated from Odum et al. (1987a) using a transformity from Odum and Arding (1991).

Agricultural, fishery, and forestry harvests were converted to energy values from Census Office, Agricultural Department, and other data. The extraction of non-renewable resources was likewise calculated from Census Office and other data and in some cases converted to energy. United States imports and exports were estimated from the annual records of the U.S. Treasury Department for commerce and navigation. The emergy of human labor embodied in imported and exported goods and services was calculated from an estimate of the average emergy embodied in paid labor. The emergy value of human services embodied in goods exported from the U.S. was estimated from the dollar value of the evaluation year's exports using the emergy-money ratio calculated for that year. The emergy-money ratio calculated in Great Britain 1860 evaluation was used with a £1.0 / \$4.9 conversion to estimate human services embodied in imports. The emergy values of the materials contained in imported and exported goods were included in the evaluation where the values were significant.

Several indices were generated from summaries of values in the United States emergy signatures, enabling comparisons of the United States system in each of the evaluation years with modern state and national systems. The empower for the United States ecologic-economic system (index U) was calculated by summing the emergy value (sej/y) of the annual inputs of rain, tide, mined materials, and of imported materials, goods, and services and subtracting materials exported without use. Other natural emergy fluxes (e.g. sunlight) that were coproducts of rain were ignored in order to avoid double counting (Odum, 1987a). The empower measurement was divided by the area of the United States. The resulting index was a measure of annual emergy per unit area (sej/m^2-y).

Emergy Evaluation of Great Britain

The ecologic-economic system of the Great Britain in 1860 was defined as the area and processes encompassed within the legal borders of England, Wales, Scotland, and Ireland and the ocean waters overlying the adjacent continental shelf to a distance of 50 km offshore. The processes within this area were then summarized as in the United States evaluations described above. The emergy utilized by the system in 1860 was taken to be the entire annual empower of the Great Britain geographic area in 1860. The driving energy flows for Great Britain were calculated as described for the U.S. evaluations as the sum of the emergy values of tide, the chemical potential energy of rain, mined material, and imports less exports. Mining production was determined from the *Abstract of British Historical Statistics* (Mitchell, 1988). Imports and exports were estimated from the *Statistical Abstract for the United Kingdom Statistical in 1860*, (GBCSO, 1872). The emergy-money ratio calculated in the U.S. 1860 evaluation was used with a $4.9 / £1.0 conversion to estimate human services embodied in imports. The emergy values of the materials contained in imported and exported goods were included in the evaluation where the values were significant.

Emergy Evaluations of the Confederate States

The ecologic-economic system of the Confederate states in 1860 (Figure 1-3) was analyzed and summarized as in the United States evaluations above. Data for trade from the Union states was estimated from Fishlow's (1964) evaluation of interregional commodity trade. All trade from Union to Confederate states was assumed to be either agricultural commodities or finished goods. All trade from Confederate to Union states was assumed to be cotton and naval stores.

The Confederate states were also analyzed for the years 1861, 1862, 1863, and 1864. Rather than presenting the full evaluation for each year, significant differences between these annual evaluations and that for 1860 were presented in a "change table." Confederate imports through the Union naval blockade (from 1861 to 1865) were estimated from various sources.

Emergy Evaluations of the Union States

The ecologic-economic system of the Union or Federal states in 1860 (Figure 1-3) was analyzed and summarized as in the U.S. and Confederate States evaluations above. The Union states were also analyzed for the years 1862, 1863, 1864, and 1865 and the significant differences presented in a "change table." The year 1861 was not analyzed because of the difficulty in separating data concerning the Confederate system from data for the Union system.

Emergy Evaluations of the Civil War

Emergy evaluations of the United States Civil War were conducted for energy flows or requirements of the War (such as munitions, fuel, and horses) and storages lost, damaged or destroyed by the War (such as infrastructure (buildings, machinery, fences, and farm equipment), livestock, and humans killed). An evaluation was conducted using War Department data (ORUCA, iii-v, pp. 961-962) from the 1864 construction of a Union steel rolling mill in order to calculate a general emergy-conversion for Confederate property destroyed during the war. The emergy of human services involved in the logistical support of the armies and navies (e.g. the teamsters, railroad workers, ship yard workers, etc. who transported supplies and made repairs) was calculated by multiplying the appropriate emergy-money ratio by a fraction of the total direct cost of the War (for either the Union or the Confederacy). Total human deaths from wounds, disease, and accidents were adjusted by subtracting the normal, peacetime mortalities.

Certain storages such as ships and cannon were recognized as embodying more emergy than was used during the War. In other words, these items still remained as storages of emergy at the end of the War, though depreciated to some extent. The full emergy value of these items was used as the requirement for the Civil War based on the assumption that the full storage of emergy was required for these items to function as tools of war.

An emergy evaluation of a hypothetical Civil War battle was also conducted. Data from the three day battle at Gettysburg, Pennsylvania (1-3 July 1863) were used. The area of the battlefield was taken to be roughly the area of the Gettysburg Battlefield Park (given by Storrick (1932) and Luvaas and Nelson (1986). Troops strengths used were those given by Nofi (1994) as those troops actually engaged in the battle. Small arms ammunition use was estimated as 60 rounds per person per day for the total number of troops engaged. Artillery ammunition use by the Union forces was taken from Union Chief of Artillery, General H.J. Hunt's. official report for the battle (ORUCA, i-xxvii). Confederate artillery ammunition use was estimated from Union use per gun. Horse and mule deaths were estimated from the number of human deaths in the battle relative to the number of human deaths in the War as a whole. An assumption that 15% of the total horse and mule deaths during the War occurred in battle was used. Disabling human injuries were estimated with the method of Beringer et al. (1986) that used French World War I statistics on the ratio of disabling wounds to total troops wounded.

CHAPTER 3
RESULTS

Calculations of Nineteenth-Century Transformities

Environmental, geologic, and human contributions to agricultural and manufacturing processes were evaluated by calculating transformities. Comparisons of these nineteenth-century transformity values with those from the twentieth century showed emergy trends over time. These trends could be analyzed for the ability of emergy to indicate factors and driving forces in technological change and the evolution of human processes.

Corn, Pork, and Cotton

The models of agricultural production used in transformity calculations for corn, pork, and cotton in 1860 are diagrammed in Figure 3-1. The transformities calculated are given in Table 3-1. The transformities were calculated to be 8.4E+04 sej/J corn, 1.0E+06 sej/J pork, and 4.4E+05 sej/J cotton. The corn transformity calculation had roughly equal emergy contributions from natural empower support (sun, wind, rain, etc.) and from human labor. The pork transformity calculation was dominated by the emergy of the corn feed consumed by the swine. This model of pork production had a negligible emergy contribution from human labor. In contrast, the calculation for the transformity of ginned cotton was largely dependent upon the emergy input from human labor, though environmental inputs were still significant. The models above were for the transformities of the products as produced rather than consumed. A true consumption transformity would include the emergy input to transporting the product.

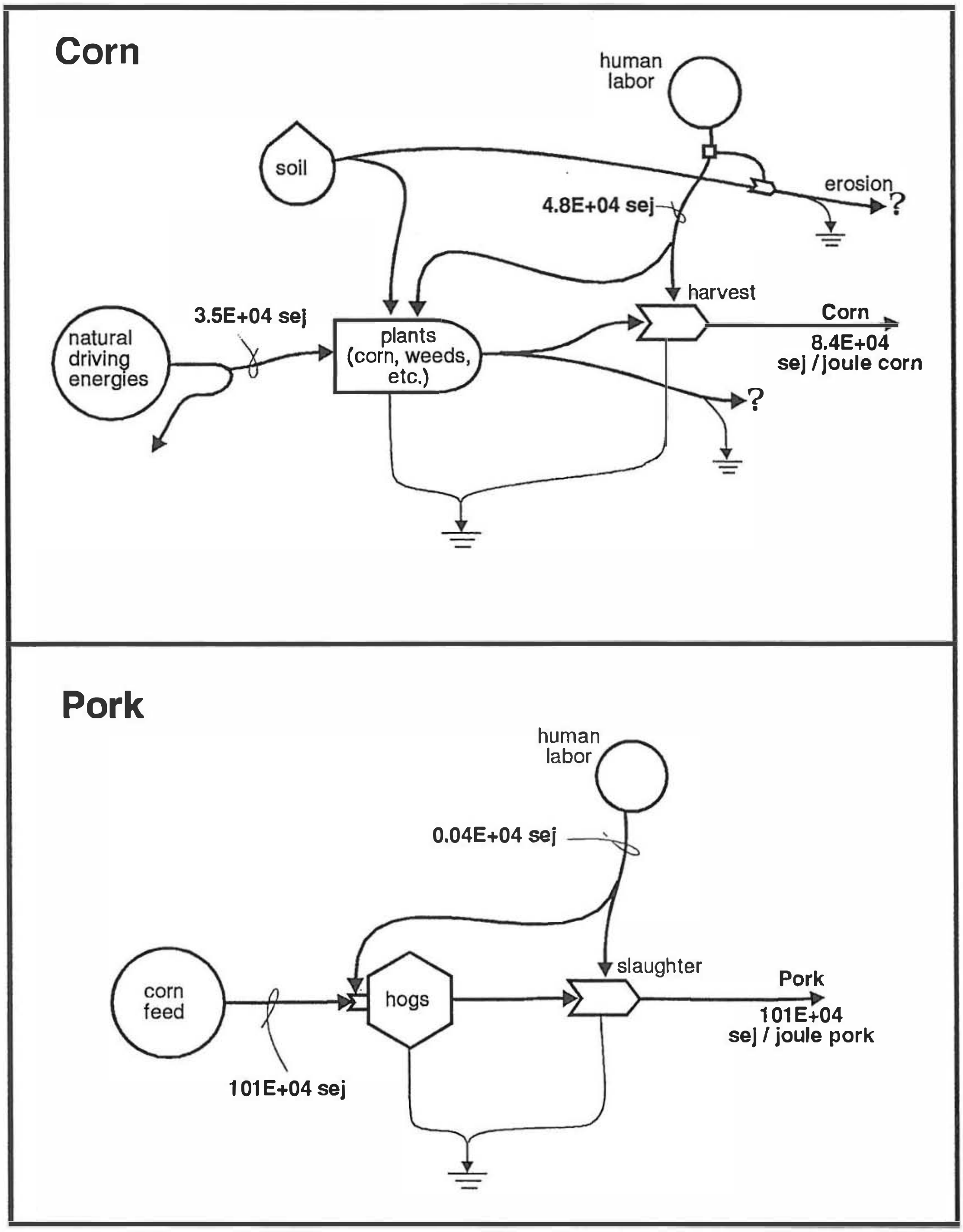


Figure 3-1. Transformity calculations for corn and pork circa 1850 - 1860.

Table 3-1. Calculations for the transformities of agricultural products circa 1850-1860.

Term	Item	Raw Units (unit / J produced)		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E4 sej/J produced)
	Corn				
1	natural empower support	4.8E-07	m^2	7.4E+10	3.5
2	labor	1.5E-09	labor-day	3.3E+13	4.8
	Corn transformity = 8.4E+04 sej/J corn (sum of 1 and 2)				
	Pork				
3	corn feed	12.1	J	8.4E+04	101
4	labor	1.2E-11	labor-day	3.3E+13	0.040
	Pork transformity = 1.0E+06 sej/J pork (sum of 3 and 4)				
	Cotton				
5	natural empower support	1.0E-06	m^2	7.4E+10	7.6
6	labor	1.1E-08	labor-day	3.3E+13	37
	Cotton transformity = 4.4E+05 sej/J cotton (sum of 5 and 6)				

Calculations in support of Table 3-1.

term:

1 Natural environmental empower (sun, wind, rain, & earth cycle)
input / J corn produced = 4.8E-07 m^2/J (from USDC (1975))
This calculation assumed a 1/2 y growing season. The empower per m^2 given was calculated from the U.S. 1860 evaluation as 1/2 of the average annual terrestrial, natural, renewable empower per m^2 (calculated as the sum of terrestrial rain and earth cycle contributions divided by the 1860 land area).

2 Labor
input / J corn produced = 1.5E-09 labor-day/J (estimated from USDC (1975) for 1850-1860)
Labor transformity was taken from the slave system evaluation.

3 Corn feed
input / J dressed pork produced = 12.1 J/J (estimated from Crampton and Harris (1969))
Dressing yields were estimated at 75% (USPO, 1846).

4 Labor
input/J dressed pork produced = 1.2E-11 labor-day/J (estimated from Fogel et al. (1992) and Genovese(1965))
Labor input was estimated from the Fogel et al. (1992) estimates for percentage of slave labor devoted to swine production and hog populations per hand for farms with 1 to 50 slaves. Hog weights at slaughter were assumed to be 140 lbs. (Genovese, 1965) and dressing yield 75% (USPO, 1846). Labor transformity was taken from the slave system evaluation.

5 Natural Empower Support
input / J cotton produced = 1.0E-06 m^2/J (from USDC (1975))
Empower per m^2 was calculated as in #1. 1860 production per acre was calculated as the weighted average of the 1840 and 1880 productions (from USDC (1975)).

6 Labor
input / J cotton produced = 1.1E-08 labor-day/J (estimated from USDC (1975) for 1850-1860)
The labor input assumed 41% of total adult field labor (estimated from Fogel & Engerman (1974)) was allocated to cotton. The percent given was for total, year-round labor (assuming maintenance labor during the fallow season) Labor transformity was taken from the slave system evaluation.

Water-Power and Steam Engine-Power

The models of 1860 water-power and steam engine-power are given in Figure 3-2. The transformities of water- and steam engine-power were calculated in Table 3-2 to be 1.4E+05 sej/J and 1.5E+06 sej/J respectively. The largest emergy input to the water-power transformity calculation was flowing water followed by machinery and material that had half the input of water. The labor input to water-power was negligible as might be expected for a major energy source for human society. The transformity calculation for steam engine-power was dominated by the emergy in the coal fuel. The emergy in the inputs of machinery and the input of labor to the generation of power by steam engine contributed 14% and 3% respectively, of the emergy in the generated power's transformity.

Gunpowder, Sulfur, and Niter

The models of production and transformity calculations for sulfur (brimstone), niter (saltpeter), and gunpowder in 1860 are given in Figure 3-3 and Table 3-3. The transformity for sulfur was calculated as 1.9E+09 sej/g, with sulfur ore as the major emergy input (81%), followed by charcoal fuel (16%), and labor (3%). The transformity calculated for niter was 3.1E+09 sej/g. Niter earth was the major empower input (95%), but fuel contributed noticeably less emergy (3%) than in the sulfur model. The transformity for gunpowder in a 75% KNO_3, 10% sulfur, and 15% carbon charcoal was calculated as 6.7E+09 sej/g and 2.0E+06 sej/J. The major emergy contributions to the transformity of gunpowder were niter (34%), steam-power (22%), and machinery (19%). This model may have excluded the emergy in transporting materials to the site of production, which could be a noticeable emergy contribution.

Lead and Lead Pig

The model of lead pig and finished lead production is given in Figure 3-4, and the lead transformities calculated from it are given in Table 3-4. The transformity of lead pig was calculated as 7.99E+09 sej/g and that of finished lead as 9.0E+09 sej/g. As might be expected in

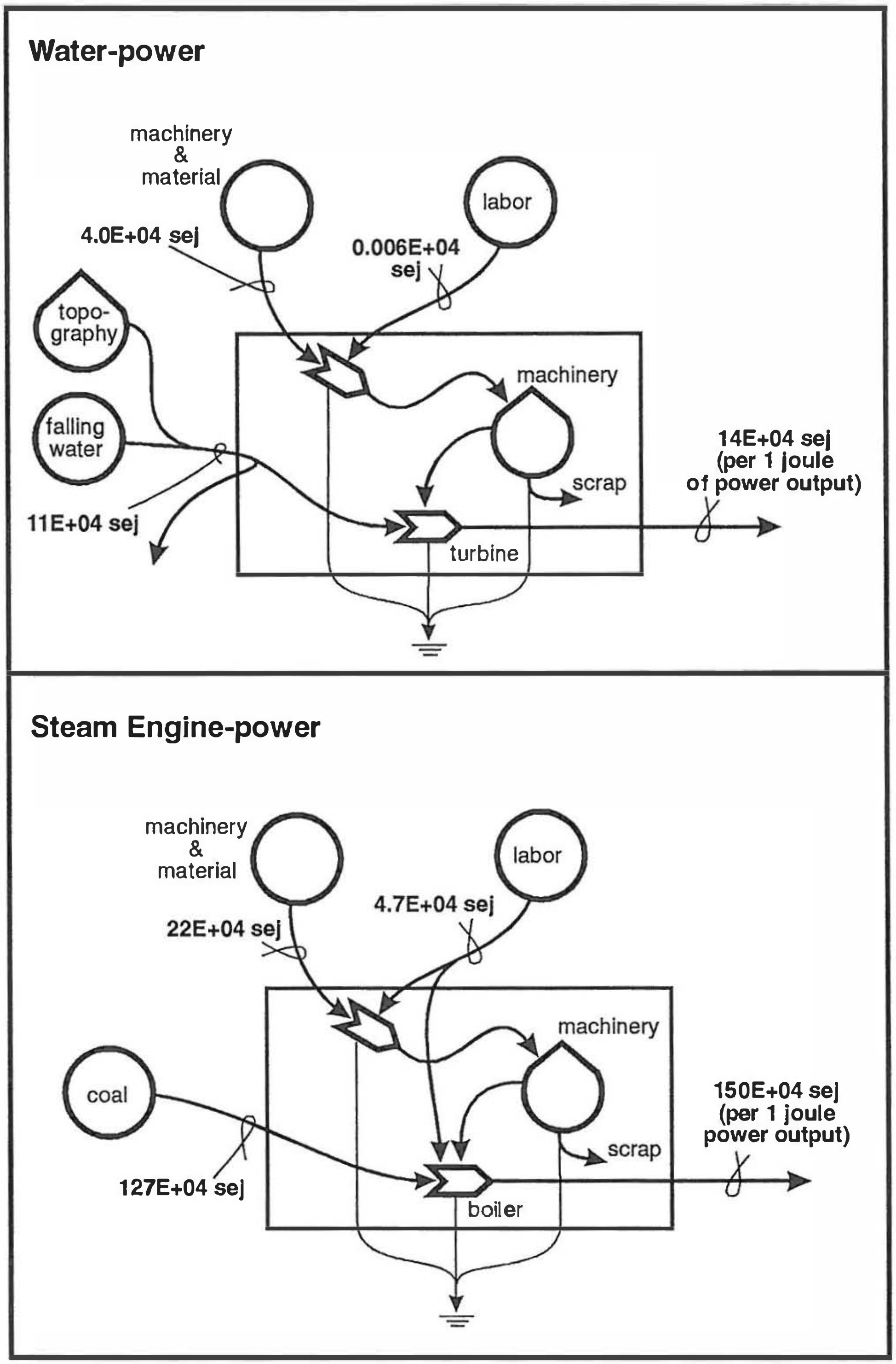


Figure 3-2. Models of water-power production and steam engine power production in the U.S. circa 1865.

Table 3-2. Calculations for the transformities of water- and steam engine-power.

Term	Item	Raw Units (unit)/J output		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (1E4 sej/J produced)
Water-power					
1	geopotential energy of water	3.0	J	3.5E+04	11
2	machinery and material	5.4E-10	$	7.4E+13	4.0
3	labor	2.6E-12	labor-day	2.3E+13	0.0060
	Water-Power transformity = 1.4E+05 sej/J power output (sum of 1 - 3)				
	Steam Engine-Power				
4	coal	38	J	3.3E+04	127
5	machinery and material	3.0E-09	$	7.4E+13	22
6	labor	2.1E-09	labor-d	2.3E+13	4.7
	Steam-power transformity = 1.5E+06 sej/J power output (sum of 4 - 6)				

Calculations in support of Table 3-2.

term:

1 Geopotential energy of flowing water

average water fall height = 5.6E+02 cm (from Gordon (1985))
water flow = 1.2E+09 cm^3 (Gordon, 1985)
water density = 1.0 g/cm^3
gravitational constant = 980 cm/s^2
harnessed power output = 4.4E+07 J (Gordon, 1985)
capacity factor = 0.50 (assumed)
Energy of falling water = (fall ht.) cm * (flow) cm^3 * (water density) g/cm^3 * (gravitational constant) cm/s^2 * 9.96E-08 J/erg
Energy of falling water = 6.6E+07 J
input / J power output = (energy of falling water) J / ((power output) J * (capacity factor))
input / J power output = 3.0 J/J
Transformity is estimated from Diamond (1984) for a fourth order stream.

2 Machinery and materials

capital in machinery = 3.8E+03 $ (estimated as 1/4 of total capital from USCO (1874))
machinery life span = 20.0 y (estimated from Williams (1870))
power output = 7.0E+11 J/y (estimated from USCO (1874))
capacity factor = 0.50 (assumed)
machinery depreciation / J output = (capital) $ / ((power output) J/y * (capacity factor) * (remaining life) y)
depreciation = 5.4E-10 $/J

3 Labor

labor / 24 operating hours. = 0.1 labor-day/J (assumed)
output / 24 operating hours. = 3.2E+10 J (Gordon (1985) assuming 0.5 capacity factor)
labor input / J power output = 2.6E-12 labor-day/J (assumed)

4 Coal: input / J output = 3.8E+01 J/J (calculated from Sopwith (1870))

5 Machinery and materials

capital in new machinery = 5.8E+03 J/J (Sopwith (1870) for 10 hp engine)
machinery life span = 11.0 y (estimated from Williams (1870))
power output = 2.3E+11 J/y (for 10 hp engine)
capacity factor = 0.75 (assumed)
machinery depreciation / J output = (capital) $ / ((power output) J/y * (capacity factor) * (remaining life) y)
depreciation = 3.0E-09 $/J

6 Labor

labor / 24 operating hours. = 1.0 labor-day/J (assumed)
output / 24 operating hours. = 4.8E+08 J (for 10 hp engine assuming 0.75 capacity factor)
labor input / J power output = 2.1E-09 labor-day/J (assumed)

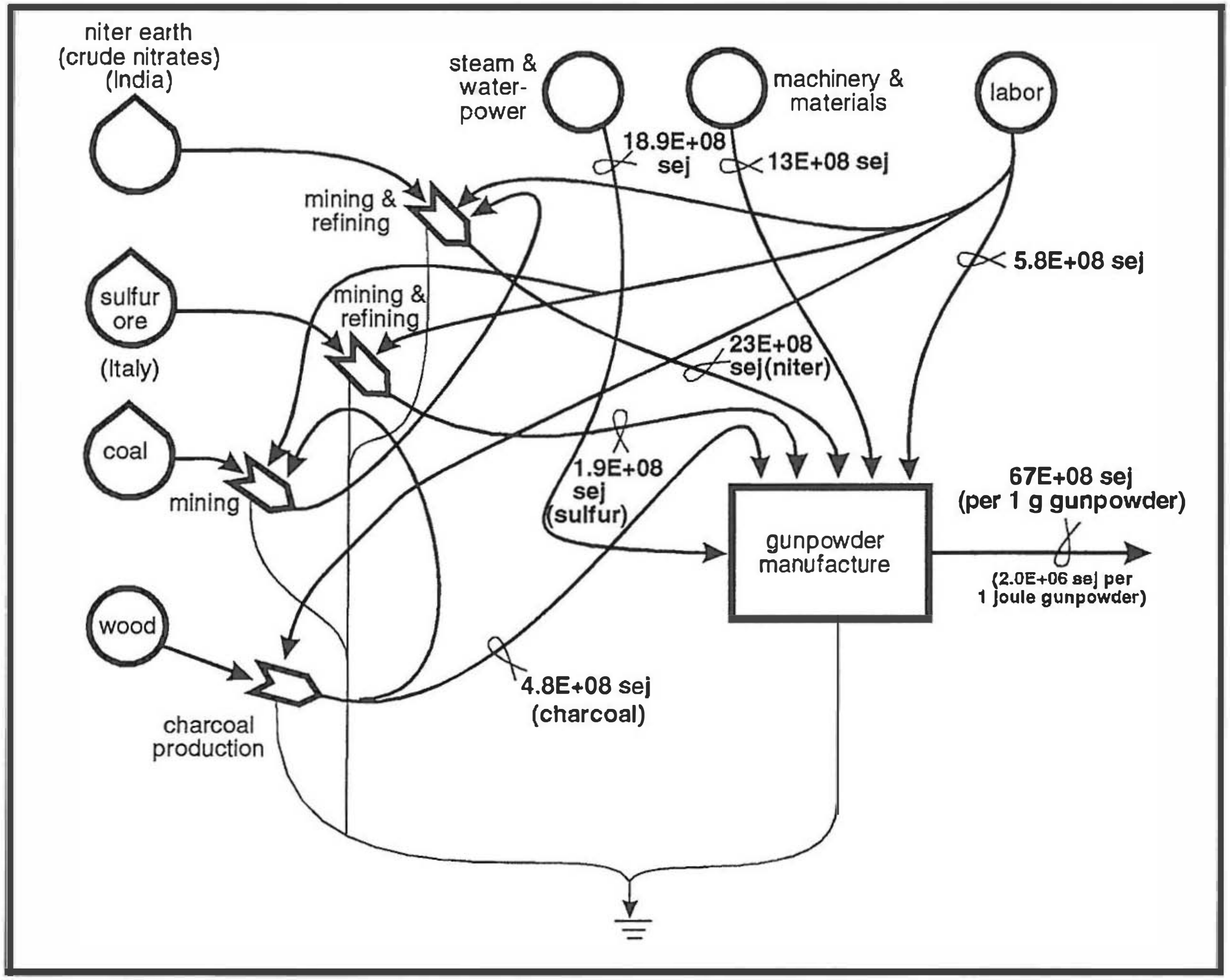


Figure 3-3. A model of 1860 gunpowder manufacture. Flows are given in sej per gram of gunpowder produced.

Table 3-3. Calculations for the transformities of sulfur, niter, and gunpowder circa 1860.

Term	Item	Raw Units (unit/g produced)	Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E8 sej/g produced)
Sulfur				
1	charcoal	2.7E+03 J	1.1E+05	2.9
2	sulfur ore	13 g	1.2E+08	15
3	labor	2.9E-06 labor-day	2.3E+13	0.66
	Sulfur transformity = 1.9E+09 sej/g sulfur (sum of 1 through 3)			
Niter or Saltpeter (Potassium Nitrate)				
4	coal	2.7E+03 J	3.3E+04	0.89
5	niter earth	13 g	2.3E+08	29
6	labor	2.9E-06 labor-day	2.3E+13	0.66
	Niter transformity = 3.1E+09 sej/g niter (sum of 4 through 6)			
Gunpowder				
7	water-power	2.8E+03 J	1.4E+05	3.9
8	charcoal	4.5E+03 J	1.1E+05	4.8
9	steam-power	9.5E+02 J	1.5E+06	15
10	sulfur	0.10 g	1.9E+09	1.9
11	niter	0.75 g	3.1E+09	23
12	labor	2.5E-05 labor-day	2.3E+13	5.8
13	machinery & materials	1.7E-05 $	7.4E+13	13
	Gunpowder transformity = 6.7E+09 sej/g gunpowder (sum of 7 through 13)			
14	**Gunpowder transformity = 2.0E+06 sej/J gunpowder**			

Calculations in support of Table 3-3.

term:			
1	Charcoal: input/g sulfur produced =	2.7E+03	J/g (estimated from Adams (1893) and Hofman (1893))
2	Sulfur ore: input/g sulfur produced =	13	g/g (estimated from Axerio (1875) and Adams (1893))
3	Labor: input/g sulfur produced =	2.9E-06	labor-day/g (Raymond, 1874)
4	Coal: input / g refined niter produced =	1.5E+04	J/g (estimated from Englehardt (1893) and Partington (1919))
5	Niter earth : input/g refined niter prod. =	29	g/g (estimated from Renwick (1836), Blount and Bloxam (1913), and Partington (1919)) This transformity is estimated from that of Florida peat from Odum (1994).
6	Labor: input/g refined niter produced =	2.9E-06	labor-day/g (estimated from that for sulfur above).
7	Waterpower		
	annual power for industry =	3.2E+13	J/y (calculated from USCO (1874))
	annual powder production =	1.2E+10	g/y (calculated from USCO (1874) and USTD (1879))
	input / g gunpowder produced =	2.8E+03	J/g
8	Charcoal: input/g gunpowder prod. =	4.5E+03	J/g (based on 15% charcoal mixture)
9	Waterpower		
	annual power for industry =	1.1E+13	J/y (calculated from USCO (1874))
	annual powder production =	1.2E+10	g/y (calculated from USCO (1874) and USTD (1879))
	input / g gunpowder produced =	9.5E+02	J/g

Table 3-3 continued.

term:			
10	Sulfur: input/g gunpowder prod. =	0.10	g/g (based on 10% sulfur mixture)
11	Niter: input/g gunpowder produced =	0.75	g/g (based on 75% niter mixture)
12	Labor		
	annual workforce for industry =	2.9E+05	labor-day/y (estimated from USCO (1874))
	annual powder production =	1.2E+10	g/y (calculated from USCO (1874) and USTD (1879))
	input / g gunpowder produced =	2.5E-05	labor-day/g
13	Machinery & Materials		
	dollar capital in industry =	4.0E+06	$ (USCO (1874))
	annual depreciation of capital =	2.0E+05	$/y (assuming 5% annual depreciation)
	annual powder production =	1.2E+10	g/y (calculated from USCO (1874) and USTD (1879))
	input / g gunpowder produced =	1.7E-05	$/g
14	Energy of gunpowder =	3300 J/g	(Faber, 1919)
	Gunpowder transformity per joule = (energy/g gunpowder)/(J/g gunpowder)		

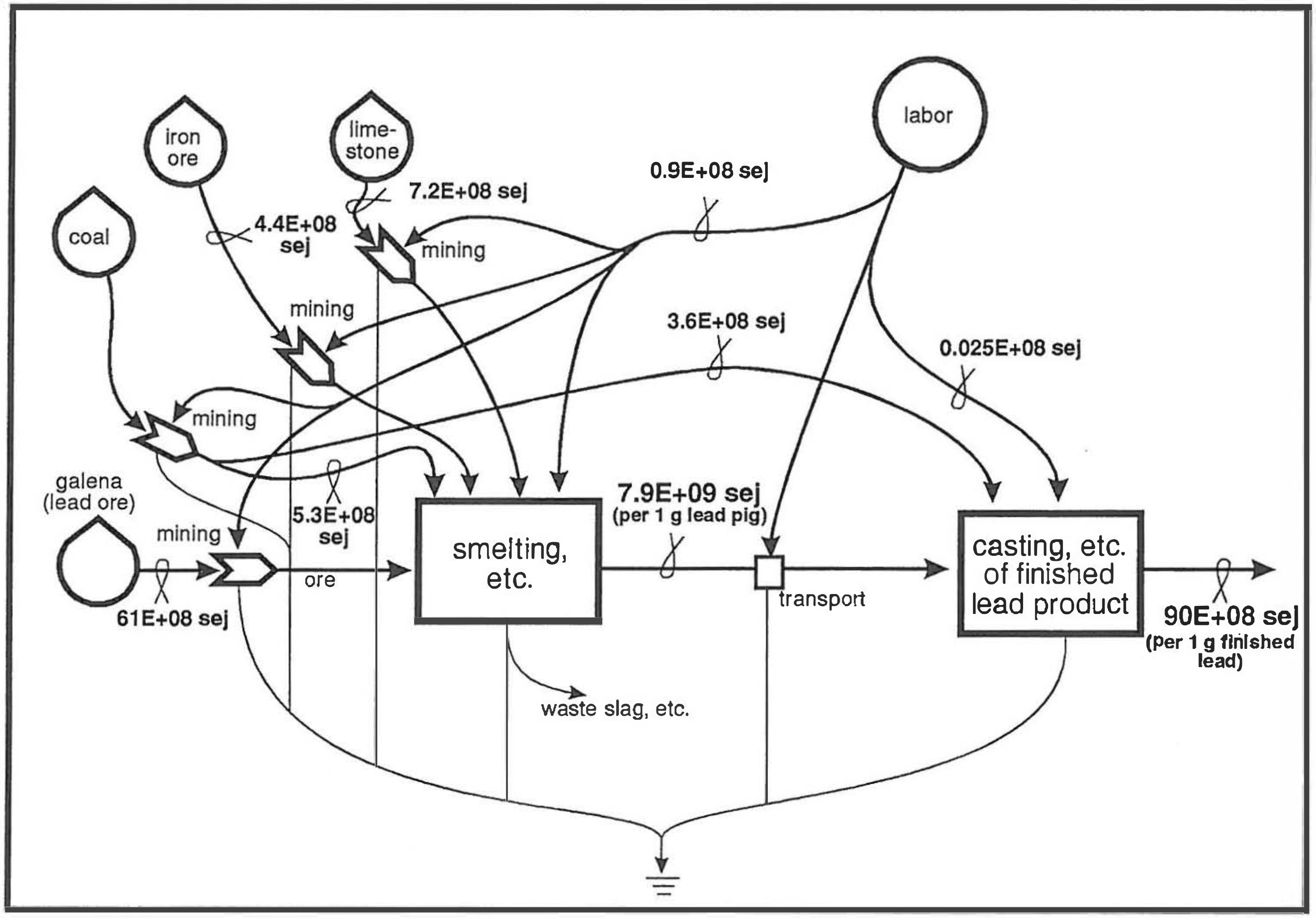


Figure 3-4. A model of 1860s lead and lead pig production from coal and galena. Flows are given in sej per gram finished lead produced.

Table 3-4. Calculations for the transformities of lead pig and lead products.

Term	Item	Raw Units (unit/g produced)		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E8 sej/g produced)
	Lead pig				
1	wood	7.4E+02	J	3.5E+04	0.26
2	coal	1.6E+04	J	3.3E+04	5.3
3	iron ore	0.56	g	7.8E+08	4.4
4	lead ore	1.4	g	4.5E+09	61
5	limestone	0.72	g	1.0E+09	7.2
6	labor (total sum)	4.0E-06	labor-day	2.3E+13	0.90
	Lead Pig transformity = 7.9E+09 sej/g lead pig (sum of 1 through 6)				
	Finished Lead Products				
7	coal	1.1E+04	J	3.3E+04	3.6
8	lead pig	1.1	g	7.9E+09	87
9	labor	1.1E-07	labor-day	2.3E+13	0.025
	Lead Products transformity = 9.0E+09 sej/g lead (sum of 7 through 9)				

Calculations in support of Table 3-4.

term:			
1	Wood: input / g lead pig produced =	7.4E+02	J/g (Hofman, 1893)
2	Coal: input / g lead pig produced =	1.6E+04	J/g (Hofman, 1893)
3	Iron Ore: input / g lead pig produced =	0.56	g/g (Raymond, 1874)
4	Lead Ore: input / g lead pig produced =	1.8	g/g (estimated from Hofman (1893))
	lead content of ore =	0.75	g/g (assumed for galena))
	lead in lead ore =	1.4	g lead in ore/g pig
5	Limestone : input / g lead pig produced =	0.72	g/g (Raymond, 1874)
6	Labor (includes labor input to mining for ore, coal, and limestone)		
	input / g lead pig produced =	4.0E-06	labor-day/g (estimated from Hofman (1893))
7	Coal: input / g lead produced =	1.1E+04	J/g (estimated from Grand (1875))
8	Lead Pig: input / g lead produced =	1.1	g/g (assumed for a 10% loss in manufacturing)
9	Labor (includes labor input to manufacturing only)		
	input / g lead produced =	1.1E-07	labor-day/g (estimated from Hofman (1893))

the harvesting or processing of a high quality raw material, the major empower input to both lead pig and finished lead was the material of interest, lead; in the form of lead ore for pig (77%), and lead pig for finished lead (96%). These transformities were for the lead as produced rather than consumed.

Iron and Pig Iron

The model of iron production used to calculate pig iron and iron product transformities is given in Figure 3-5 and the results of the calculations in Table 3-5. The transformity of pig iron was calculated as 4.6E+09 sej/g and that of finished iron as 1.1E+10 sej/g or 6.5E+08 sej/J. These transformities were different from the lead transformities in that the raw product, iron, was not the overwhelming emergy contributor of the transformity. Iron in iron ore contributed 21% of the emergy in pig iron as compared to the 55% contributed by coal fuel and the 22% contributed by limestone flux. Pig iron contributed 57% of the emergy in finished iron, but coal fuel was still a major contributor (40%). The different geologic histories of iron and lead ores may explain these differing models of their transformities. As in the previous models, these were transformities of production rather than consumption.

Emergy Evaluations of the United States in 1850, 1860, and 1870

The United States in 1850

The results of the emergy evaluation of the United States in 1850 are given in Tables 3-6, 3-7, and 3-8. The emergy signature of the U.S. in 1850 is given in Table 3-6. The calculations for this signature are detailed in Appendix B. Table 3-7 gives a summary of several categories of related flows from the emergy signature. The primary renewable sources of emergy (R, Table 3-7) were rain, waves, tide, and the earth cycle. The most significant methods of harvesting or capturing these renewable flows were through livestock agriculture (terms 17, 19, and 20,

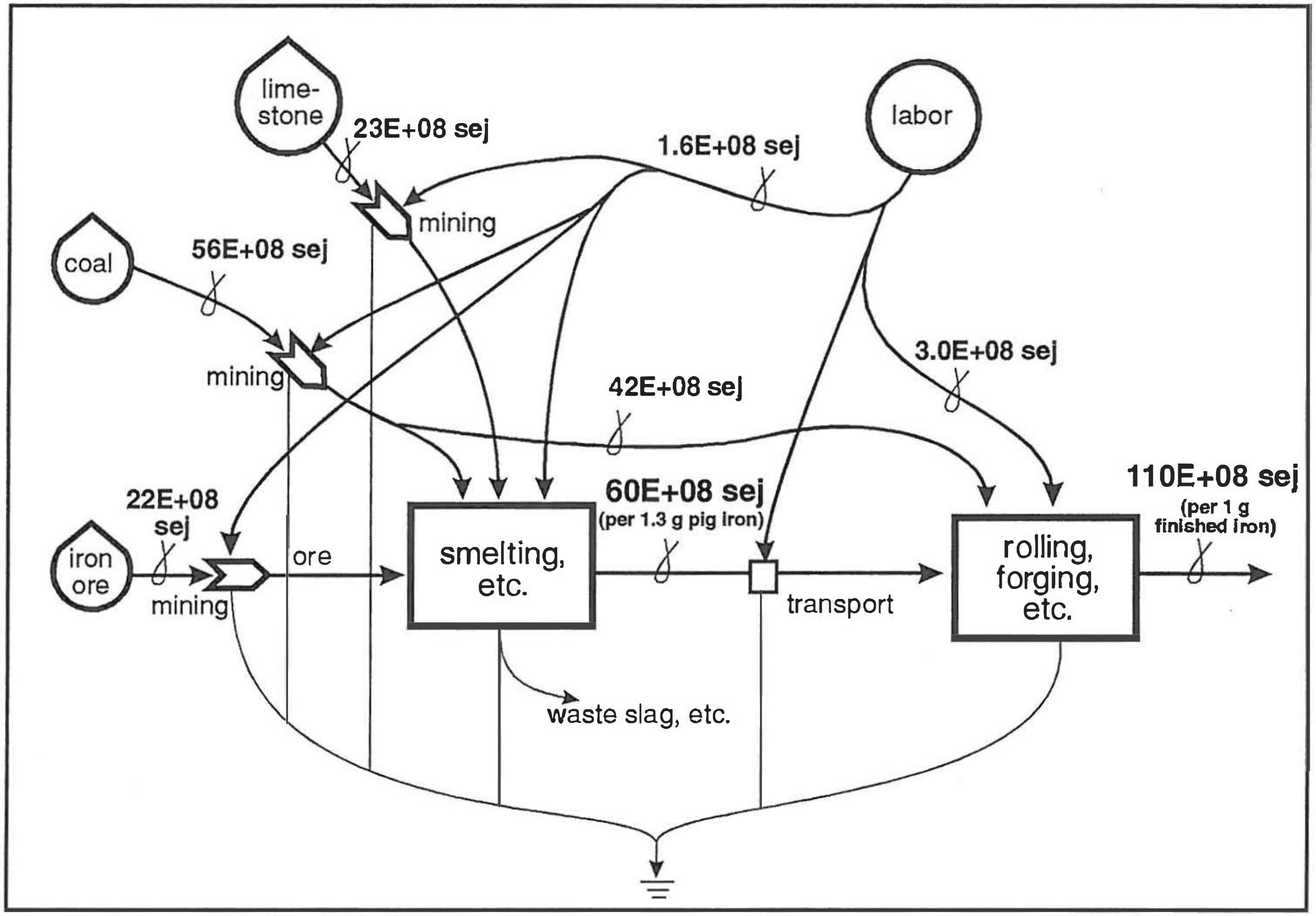


Figure 3-5. A model of 1860 iron and pig iron production from coal.
Flows are given in sej per gram finished iron produced.

Table 3-5. Calculations for the transformities of pig iron and iron products.

Term	Item	Raw Units (unit/g produced)		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E8 sej/g produced)
	Pig Iron				
	coal	1.7E+05	J	3.3E+04	56
	iron in iron ore	2.2	g	1.0E+09	22
	limestone	2.3	g	1.0E+09	23
	labor (total sum)	7.1E-06	labor-day	2.3E+13	1.6

Pig Iron transformity = 4.6E+09 sej/g pig iron
(sum of 1 - 4)

Term	Item	Raw Units (unit/g produced)		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E8 sej/g produced)
	Iron and Iron Products				
5	coal	1.3E+05	J	3.3E+04	42
6	pig iron	1.3	g	4.6E+09	60
7	labor	1.3E-05	labor-day	2.3E+13	3.0

Iron transformity = 1.1E+10 sej/g iron
(sum of 5 - 7)

8 **Iron transformity = 6.5E+08 sej/J iron**

Calculations in support of Table 3-5.

term:

1 Coal
input / g pig iron produced = 1.7E+05 J/g (estimated from Anonymous (1837))
Transformity is for mineral coal. Mining labor is accounted for in the overall labor input (#4).

2 Iron Ore
input / g pig iron produced = 3.0 g/g (estimated from Fairbairn (1861))
iron content of ore = 0.72 g/g (from Fairbairn (1861) for U.S. ores)
iron in iron ore = 2.2 g iron in ore/g pig
Transformity assumes ore is of sedimentary origin.

3 Limestone
input / g pig iron produced = 2.3 g/g (estimated from Samuelson (1871))

4 Labor (includes labor input to mining for ore, coal, and limestone)
input / g pig iron produced = 7.1E-06 labor-day/g (estimated from USCO (1864))
Transformity from U.S.A. 1860 evaluation assuming a 6 day workweek with 20 lost days per year.

5 Coal
input / g iron produced = 1.3E+05 J/g (estimated from pig iron production)
Transformity is for mineral coal. Mining labor is accounted for in the overall labor input (#7).

6 Pig Iron
input / g iron produced = 1.3 g/g (estimated from USCO (1864))

7 Labor (includes labor input to manufacturing only)
input / g iron produced = 1.3E-05 labor-day/g (estimated from USCO (1864))
Transformity from U.S.A. 1860 evaluation assuming a 6 day workweek with 20 lost days per year.

8 Free energy of iron estimated at 16.2 J/g from Odum (1994)

Table 3-6. Emergy evaluation of the United States in 1850.

Term	Item	Raw Units (J,$ or g)/y		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E20 sej/y)
RENEWABLE RESOURCES:					
1	Sunlight	4.2E+21	J	1	42
2	Wind, kinetic	2.3E+19	J	620	142
3	Rain, geopotential	4.9E+18	J	8900	438
4	Rain, chemical	4.4E+18	J	15000	667
5	Tide	5.0E+17	J	24000	120
6	Waves	2.5E+18	J	26000	661
7	Earth cycle	1.3E+18	J	29000	380
INDIGENOUS RENEWABLE ENERGY:					
8	Hydro-power	1.7E+16	J	8900	1.5
9	Plant leaf & fiber products	1.8E+17	J	27000	50
10	Breadstuffs & grains	3.6E+17	J	27000	96
11	Fruit & root crops	1.1E+16	J	27000	3.0
12	Ginned cotton	8.0E+15	J	27000	2.2
13	Sugar & molasses	2.5E+15	J	27000	0.70
14	Forest extraction	1.4E+17	J	8000	11
15	Fuelwood Use	2.4E+18	J	8000	189
16	Shellfish fisheries	1.3E+13	J	8.0E+05	0.10
17	Butter & cheese	4.8E+15	J	1.3E+06	62
18	Finfish fisheries	8.2E+14	J	2.0E+06	16
19	Livestock production	6.6E+15	J	2.0E+06	132
20	Wool	3.8E+14	J	3.8E+06	14
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:					
21	Soil loss	2.5E+17	J	6.3E+04	159
22	Coal extraction	2.3E+17	J	3.3E+04	75
23	Iron ore	1.6E+12	g	1.0E+09	16
24	Lead, copper, & mercury	2.2E+10	g	4.2E+09	0.94
25	Gold & silver	7.5E+07	g	5.0E+09	0.0039
IMPORTS AND OUTSIDE SOURCES:					
26	Sugar, & other plant products	5.7E+15	J	2.7E+04	1.5
27	Coal	6.0E+15	J	3.3E+04	2.0
28	Fisheries & fish oils	9.1E+13	J	2.0E+06	1.8
29	Whale oil & bone	1.7E+14	J	3.6E+07	62
30	Plant derived ash & soda	3.6E+10	g	2.2E+08	0.081
31	Iron & iron products	3.6E+11	g	7.6E+09	26.9
32	Lead, chalk, & their products	2.2E+10	g	7.6E+09	1.7
33	Gold & silver coin	5.3E+06	g	1.4E+14	7.4
34	Additional services in imports	2.1E+08	$	6.7E+13	138
35	Net immigration	3.7E+05	people	1.2E+17	452
EXPORTS:					
36	Plant leaf & fiber products, grain & breadstuffs	5.0E+15	J	8.2E+04	4.1
37	Wood & wood products	1.8E+17	J	3.5E+04	65
38	Coal export	1.0E+15	J	3.3E+04	0.30
39	Cotton	6.4E+15	J	4.4E+05	28
40	Other animal products	1.1E+15	J	1.8E+06	20
41	Fisheries products	1.0E+15	J	2.0E+06	21
42	Whale products	6.6E+13	J	3.6E+07	24
43	Iron & iron product	2.9E+09	g	7.6E+09	0.22
44	Gold, coin & bullion	2.6E+07	g	4.4E+14	117
45	Additional services in exports	2.0E+08	$	8.3E+13	169.

Calculations in support of Table 3-6 are given in Appendix B.

Table 3-7. Summary of 1850 United States annual empower and money flows from Table 3-6.

Term	Item	Solar Emergy (E20 sej/y)	Dollars E+07 $	sej/$
R	Renewable Sources (rain, tide, earth cycle)	1166		
N	Nonrenewable Sources from with in U.S.	251		
N0	Dispersed Rural Sources	159		
N1	Concentrated Emergy Use	671		
N2	Emergy Exported without Use	0.35		
F + G	Imported Fuels, Minerals & Goods	103		
I	Dollars Paid for Imports		22	
P2I	Emergy Value of Service in Imports	145		
E	Dollars Received for Exports		23	
P1E	Emergy Value of Service in Exports	190		
B	Emergy of Exports	278		
GNP	U.S. Gross National Product (1850)		200	
P2	World Emergy-Money Ratio, used in imports			6.7E+13
P1	U.S.A. 1850 Emergy-Money Ratio			8.3E+13
U	Total Emergy Use	1658		
fuel	Emergy of Fossil Fuel Use	77		

Term Derivations (numbers refer to terms in Table 3-6):

term:
R = 4 + 5 + 7
N = 21 + 22 + 23 + 24 + 25
N0 = 21
N1 = 8 + 9 + 10 + 11 + 12 + 13 + 14+ 15 + 16 + 17 + 18 + 19 + 20
N2 = 38 + 43
F + G = 26 + 27 + 28 + 29 + 30 + 31 + 32 + 33
I = (total value of imports in calculations supporting Table 3-6)
P2I = I * P2
E = (total value of exports in calculations supporting Table 3-6)
P1E = E * P1
B = 36 + 37 + 38 + 39 + 40 + 41 + 42 + 43 + 44
GNP = from Gallman (1966)
P2 = from Great Britain 1860 evaluation
P1 = I20 (Table 3-8)
U = R + N + F + G + 34 - N2
fuel = 22 + 27 - 38

Table 3-8. United States 1850 emergy indices derived from Table 3-7.

Term	Name of Index	Expression[a]	Quantity	
I1	Renewable emergy	R	1166	E+20 sej/y
I2	Indigenous non-renewable emergy	N	251	E+20 sej/y
I3	Flow of imported emergy	F+G+34	248	E+20 sej/y
I4	Total emergy inflows	R+N+F+G+34	1658	E+20 sej/y
I5	Total emergy used, U	R+N+F+G+34-N2	1658	E+20 sej/y
I6	Economic component	U-R	492	E+20 sej/y
I7	Total exported emergy	B+45	468	E+20 sej/y
I8	% Locally renewable	R/U *100%	70	%
I9	Economic/environment ratio	(U-R)/R	0.42	
I10	Ratio of imports to exports	(F+G+34)/(B+45)	0.53	
I11	Ratio of export to imports	(B+45)/(F+G+34)	1.9	
I12	Imports minus exports	(F+G+34)-(B+45)	-220	E+20 sej/y
I13	% of emergy use imported	(F+G+34)/U *100%	15	%
I14	Fraction imported service	P2I/U	0.088	
I15	% of emergy use derived from home sources	(U-F-G-34)/U * 100%	85	%
I16	% of use that is free	(R+N0)/U	80	%
I17	Ratio of concentrated/rural	(F+G+34+N1)/(R+N0)	0.693	
I18	Empower density	U/(area)[b]	1.4E+11	sej/m^2
I19	Use per person	U/population[c]	6.8E+15	sej/person
I20	Ratio of use to GNP,	P1 = U/GNP	8.3E+13	sej/$
I21	Fraction fossil fuels	(fuel)/U	0.046	
I22	Fossil fuel use per person	fuel/population[c]	3.2E+14	sej/person

[a] Expressions refer to terms in Tables 3-6 and 3-7.

[b] 1850 farm area = 1.19E+12 m^2 (from USCO (1854))

[c] 1850 population = 2.43E+07 people (USCO, 1854)

Table 3-6) and forest extraction of timber and fuelwood (terms 14 and 15, Table 3-6). Whale and iron products (terms 29 and 31, Table 3-6) had the largest emergy values among the imports analyzed. During this period, whale oil was a primary source of fuel for illumination. Illumination seems to have been a high quality process during this period in the nineteenth century, and seems to have attracted a high emergy source of fuel. Human immigration (term 35, Table 3-6) also had a large emergy value, but this value represented a storage that was not consumed to a great extent during the year of evaluation. Only the flow of services from these humans was consumed, not the humans themselves. Because of this, immigration was not included in the following summary tables and indices for any of the evaluations in this study.

Table 3-8 gives several emergy indices derived from the summary flows. The empower density of the United States in 1850 was calculated as 1.4E+11 sej/m^2 (term I18, Table 3-8). This value is virtually identical to that in the 1860 evaluation (term I18, Table 3-11) and the 1870 evaluation (term I18, Table 3-13). The 1850 U.S. emergy-money ratio was 8.3E+13 sej/$ and the per capita emergy was 6.8E+15 sej/person (terms I20 and I19, Table 3-8).

The United States in 1860

A model of the nineteenth-century United States is diagrammed in Figure 3-6. The terms in this model correspond to those of the 1860 U.S. evaluation, but the model is valid for all the U.S. evaluations as well as the evaluations of Great Britain, the Confederate States, and the Union states if the corresponding terms are substituted.

The results of the emergy evaluation of the United States in 1860 are given in Tables 3-9, 3-10, and 3-11. The emergy signature of the U.S. in 1860 is given in Table 3-9. The calculations in support of this signature are detailed in Appendix C. Table 3-10 gives a summary of several categories of related flows derived from the emergy signature. As in the 1850 evaluation, the primary renewable sources of emergy (R, Table 3-10) were rain, waves, tide, and the earth cycle. The import of whale products (term 30, Table 3-9) was significantly less than in 1850. Among the

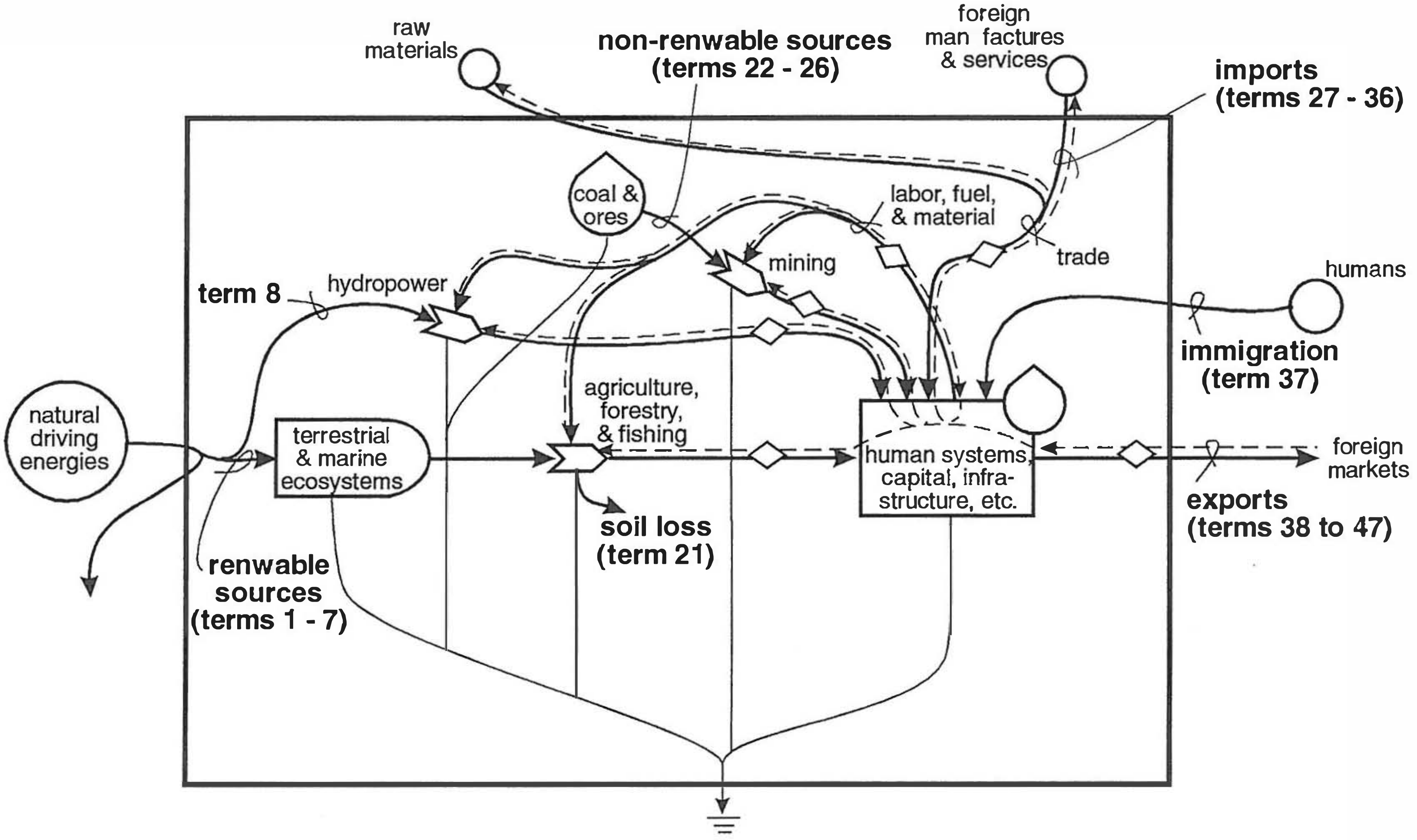


Figure 3-6. An aggregated model of the United States in 1860 showing the flows to which the terms in Table 3-9 correspond.

Table 3-9. Emergy evaluation of the United States in 1860.

Term	Item	Raw Units (J,$, or g)/y	Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E20 sej/y)
RENEWABLE RESOURCES:				
1	Sunlight	5.6E+21 J	1	56.
2	Wind, kinetic	4.9E+19 J	620	303.
3	Rain, geopotential	6.8E+18 J	8900	607.
4	Rain, chemical	5.8E+18 J	15000	873.
5	Tide	5.3E+17 J	24000	128.
6	Waves	3.1E+18 J	26000	801.
7	Earth cycle	1.8E+18 J	29000	526.
INDIGENOUS RENEWABLE ENERGY:				
8	Hydro-power	2.1E+16 J	8900	1.9
9	Plant leaf & fiber production	2.5E+17 J	27000	69
10	Breadstuffs & grains	2.6E+17 J	27000	71
11	Fruit & root crops	8.7E+15 J	27000	2.4
12	Ginned cotton	1.4E+16 J	270000	3.8
13	Sugar & molasses	1.1E+16 J	27000	2.9
14	Forest extraction	2.0E+17 J	8000	15.9
15	Fuelwood Use	2.4E+18 J	8000	189
16	Shellfish fisheries	3.5E+13 J	8.0E+05	0.28
17	Butter & cheese	6.4E+15 J	1.3E+06	83
18	Finfish fisheries	5.1E+13 J	2.0E+06	1.0
19	Livestock production	8.4E+15 J	2.0E+06	168
20	Wool	4.3E+14 J	3.8E+06	16
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:				
21	Soil loss	3.6E+17 J	6.3E+04	229
22	Coal extraction	3.9E+17 J	3.3E+04	129
23	Crude petroleum	3.1E+15 J	5.3E+04	1.6
24	Iron ore	2.4E+12 g	1.0E+09	24
25	Copper, lead, nickel, & zinc ores, mercury, & silver	4.1E+10 g	4.4E+09	1.8
26	Gold & Silver	7.3E+07 g	5.0E+09	0.0037
IMPORTS AND OUTSIDE SOURCES:				
27	Sugar, fruits, & other plant products	7.9E+15 J	2.7E+04	2.1
28	Coal	6.7E+15 J	3.3E+04	2.2
29	Fisheries & fish oils	2.2E+13 J	2.0E+06	0.45
30	Whale oil & bone	1.3E+14 J	3.6E+07	47.
31	Plant derived ash & soda	5.1E+10 g	2.2E+08	0.12
32	Iron & iron products	3.6E+11 g	7.5E+09	28.
33	Chalk, brimstone, & lead, & their products	4.4E+10 g	4.3E+09	1.9
34	Silver coin	9.0E+07 g	6.5E+12	5.9
35	Gold coin	2.1E+06 g	1.4E+14	3.0
36	Services embodied in imports	3.4E+08 $	6.7E+13	232
37	Net immigration	1.5E+05 people	1.2E+17	188
EXPORTS:				
38	Grains, breadstuffs, & other plant products	6.7E+15 J	8.0E+04	5.2
39	Wood & wood products	9.0E+16 J	3.5E+04	31
40	Coal	5.2E+15 J	3.3E+04	1.7
41	Cotton	1.2E+16 J	4.4E+05	51.
42	Other animal products	8.4E+14 J	1.7E+06	15
43	Fisheries products	5.2E+15 J	2.0E+06	105
44	Whale products	5.1E+13 J	3.6E+07	19
45	Iron & iron products	8.3E+09 g	7.5E+09	0.63
46	Gold & silver coin & bullion	4.1E+07 g	2.2E+14	91
47	Services embodied in exports	1.1E+08 $	7.4E+13	80

Calculations in support of Table 3-9 are given in Appendix C.

Table 3-10. Summary of 1860 United States annual empower and money flows from Table 3-9.

Term	Item	Solar Emergy (E20 sej/y)	Dollars E+07 $	sej/$
R	Renewable Sources (rain, tide)	1527		
N	Nonrenewable sources from with in U.S.	386		
N0	Dispersed Rural Sources	229		
N1	Concentrated Use	780		
N2	Emergy Exported without Use	2		
F + G	Imported Fuels, Minerals & Goods	91		
I	Dollars Paid for Imports		36	
P2I	Emergy Value of Service in Imports	243		
E	Dollars Received for Exports		40	
P1E	Emergy Value of Service in Exports	295		
B	Exports	319		
GNP	U.S. Gross National Product (1860)		303	
P2	World Emergy-Money Ratio, used in imports			6.7E+13
P1	U.S. 1860 Emergy-Money Ratio			7.4E+13
U	Total System Emergy Use	2234		
fuel	Emergy of Fossil Fuel Use	131		

Term Derivations (numbers refer to terms in Table 3-9):

term:
R = 4 + 5 + 7
N = 21 + 22 + 23 + 24 + 25 + 26
N0 = 21
N1 = 8 + 9 + 10 + 11 + 12 + 13 + 14 + 15 + 16 + 17 + 18 + 19 + 20
N2 = 40
F + G = 27 + 28 + 29 + 30 + 31 + 32 + 33 + 34 + 35
I = (total value of imports in calculations supporting Table 3-9)
P2I = I * P2
E = (total value of exports in calculations supporting Table 3-9)
P1E = E * P1
B = 38 + 39 + 40 + 41 + 42 + 43 + 44 + 45 + 46
GNP = from Gallman (1966)
P2 = from Great Britain 1860 evaluation
P1 = 120 (Table 3-11)
U = R + N + F + G + 36 - N2
fuel = 22 + 23 + 28 - 40

Table 3-11. United States 1860 emergy indices derived from Table 3-10.

Term	Name of Index	Expression[a]	Quantity	
I1	Renewable emergy	R	1527	E+20 sej/y
I2	Indigenous non-renewable emergy	N	386	E+20 sej/y
I3	Flow of imported emergy	F+G+36	322	E+20 sej/y
I4	Total emergy inflows	R+N+F+G+36	2236	E+20 sej/y
I5	Total human system emergy, U	R+N+F+G+P2I-B-47	2234	E+20 sej/y
I6	Economic component	U-R	707	E+20 sej/y
I7	Total exported emergy	B+47	399	E+20 sej/y
I8	% Locally renewable	R/U *100%	68	%
I9	Economic/environment ratio	(U-R)/R	0.46	
I10	Ratio of imports to exports	(F+G+36)/(B+47)	0.80	
I11	Ratio of export to imports	(B+47)/(F+G+P2I)	1.2	
I12	Imports minus exports	(F+G+36)-(B+47)	-77	E+20 sej/y
I13	% of emergy use purchased	(F+G+36)/U *100%	14	%
I14	Fraction imported service	P2I/U	0.11	
I15	% of emergy use derived from home sources	(U-F-G-36)/U * 100%	85	%
I16	% of use that is free	(R+N0)/U	79	%
I17	Ratio of concentrated/rural	(F+G+36+N1)/(R+N0)	0.63	
I18	Empower density (of farmed area)	U/(area)[b]	1.4E+11	sej/m^2
I19	Use per person	U/(population)[c]	7.1E+15	sej/person
I20	Ratio of use to GNP,	P1 = U/GNP	7.4E+13	sej/$
I21	Fraction fossil fuels	(fuel)/U	0.059	
I22	Fossil fuel use per person	(fuel)/(population)[c]	4.2E+14	sej/person

[a] Expressions refer to terms in Tables 3-9 and 3-10.

[b] 1860 farm area = 1.65E+12 m^2 (from USCO (1864))

[c] 1860 population = 3.14E+07 people (USCO, 1864)

exports with the largest emergy values are wood, raw cotton, animal products, and fish (terms 39, 41, 42, 43, and 44, Table 3-9), all of which are raw materials.

Table 3-11 gives several emergy indices derived from the summary flows. The U.S. emergy-money ratio in 1860 was calculated to be smaller than the 1850 emergy-money ratio at 7.4E+13 sej/$, while the per capita emergy of 7.1E+13 sej/person was larger than that of 1850 (terms I18, I20, and I19, Tables 3-8 and 3-11). The percent of emergy from locally renewable sources stayed fairly constant from 1850 (70%) to 1860 (68%) (terms I8, Tables 3-8 and 3-11). The ratio of the emergy in imports verses exports did increase significantly from 0.42 in 1850 to 0.80 in 1860 (terms I9, Tables 3-8 and 3-11).

The United States in 1870

The results of the emergy evaluation of the United States in 1870 are given in Tables 3-12, 3-13, and 3-14. The emergy signature calculated for the U.S. in 1870 is given in Table 3-12. The calculations in support of this signature are detailed in Appendix D. Table 3-13 gives a summary of several categories of related flows derived from the emergy signature. Coal, petroleum, iron, and silver extraction increased significantly from 1860 (terms 22, 23, 24, and 26, Table 3-12). This increase in petroleum extraction was the result of the boom following the discovery of oil in Pennsylvania in the late 1850s, while the increase in silver extraction was the result of the development of the Comstock lode in Nevada. However, 1870 exports were still dominated by raw material.

Table 3-14 gives several emergy indices derived from the summary flows. The U.S. emergy-money ratio in 1870 was calculated as 3.0E+13 sej/$, significantly less than the 7.4E+13 sej/$ value in 1860 (terms I20, Tables 3-11 and 3-14). This change may have been the result of lingering war-time inflation. The per capita emergy value of 6.5E+15 sej/person was also less than the 7.4E+13 1860 value (terms I19, Tables 3-11 and 3-14). This lower per capita emergy value suggests that more than inflation was behind the decrease in the 1870 emergy-money ratio. The annual fossil fuel use per person increased slightly from 3.2E+14 sej/person in 1850 to

Table 3-12. Emergy evaluation of the United States in 1870.

Term	Item	Raw Units (J,$ or g)/y		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E20 sej/y)
RENEWABLE RESOURCES:					
1	Sunlight	5.6E+21	J	1	56
2	Wind, kinetic	6.2E+18	J	620	39
3	Rain, geopotential	6.8E+18	J	8900	607
4	Rain, chemical	5.8E+18	J	15000	873
5	Tide	5.3E+17	J	24000	128
6	Waves	3.1E+18	J	26000	801
7	Earth cycle	1.8E+18	J	29000	526
INDIGENOUS RENEWABLE ENERGY:					
8	Hydro-power	2.7E+16	J	8900	2.4
9	Plant leaf & fiber prod.	3.6E+17	J	27000	97
10	Breadstuffs & grains	2.9E+17	J	27000	79
11	Fruit & root crops	9.4E+15	J	27000	2.5
12	Ginned cotton	7.9E+15	J	27000	2.1
13	Sugar & molasses	2.0E+15	J	27000	0.55
14	Forest extraction	3.0E+17	J	8000	24
15	Fuelwood Use	3.2E+18	J	8000	256
16	Shellfish fisheries	3.5E+13	J	8.0E+05	0.28
17	Butter & cheese	6.5E+15	J	1.3E+06	84
18	Finfish fisheries	n.a.	J	2.0E+06	—
19	Livestock production	7.8E+15	J	2.0E+06	157
20	Wool	7.2E+14	J	3.8E+06	27
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:					
21	Soil loss	4.2E+17	J	6.3E+04	267
22	Coal extraction	1.1E+18	J	3.3E+04	365
23	Crude petroleum	3.2E+16	J	5.3E+04	17
24	Iron ore	5.4E+12	g	1.0E+09	54
25	Copper, lead, zinc, & mercury	3.8E+10	g	4.3E+09	1.6
26	Silver	3.8E+08	g	5.0E+09	0.019
27	Gold	7.5E+07	g	5.0E+09	0.0038
IMPORTS AND OUTSIDE SOURCES:					
28	Sugar, molasses, & other plant products	1.3E+16	J	2.7E+04	3.6
29	Coal	1.2E+16	J	3.3E+04	3.9
30	Fisheries & fish oils	8.9E+13	J	2.0E+06	1.8
31	Plant derived ash & soda	9.4E+10	g	2.2E+08	0.2
32	Iron & iron products	5.3E+11	g	7.6E+09	40
33	Lead, brimstone, lime, & their products	7.8E+10	g	5.1E+09	4.0
34	Silver coin and bullion	3.6E+08	g	6.5E+12	24.
35	Gold coin & bullion	2.6E+07	g	1.4E+14	37
36	Services embodied in imports	2.9E+08	$	6.7E+13	194
37	Net immigration	3.9E+05	people	1.2E+17	474
EXPORTS:					
38	Grains, & other plant products	2.8E+16	J	8.1E+04	24
39	Wood & wood products	6.5E+16	J	3.5E+04	23
40	Coal export	6.3E+15	J	3.3E+04	2.1
41	Cotton	6.7E+15	J	4.3E+05	29
42	Other animal products	1.2E+16	J	1.6E+06	19
43	Fisheries products	6.3E+15	J	2.0E+06	127
44	Whale products	1.8E+13	J	3.6E+07	6.3
45	Iron & iron product	3.8E+09	g	7.6E+09	0.29
46	Silver coin and bullion	6.5E+08	g	1.4E+12	9.1
47	Gold, coin & bullion	3.7E+07	g	4.4E+14	165
48	Services embodied in exports	5.0E+08	$	3.0E+13	141

Calculations in support of Table 3-12 are given in Appendix D.

Table 3-13. Summary of 1870 United States annual empower and money flows from Table 3-12.

Term	Item	Solar Emergy (E20 sej/y)	Dollars E+07 $	sej/$
R	Renewable Sources (rain, tide)	1527		
N	Nonrenewable Sources from with in U.S.	704		
N0	Dispersed Rural Source	267		
N1	Concentrated Use	1167		
N2	Emergy Exported Without Use	2.1		
F +G	Imported Fuels, Minerals & Goods	114		
I	Dollars Paid for Imports		29	
P2I	Emergy Value of Service in Imports	193		
E	Dollars Received for Exports		50	
P1E	Emergy Value of Service in Exports	151		
B	Emergy in Exports	403		
GNP	U.S. Gross National Product (1870)		830	
P2	World Emergy-Money Ratio, used in imports			6.7E+13
P1	U.S.A. 1870 Emergy-Money Ratio			3.0E+13
U	Total Emergy Use	2510		
fuel	Emergy of Fossil Fuel Use	384		

Term Derivations (numbers refer to terms in Table 3-12):

term:
R = 4 + 5 + 7
N0 = 21
N = 21 + 22 + 23 + 24 + 25 + 26 + 27
N1 = 8 + 9 + 10 + 11 + 12 + 13 + 14 + 15 + 16 + 17 + 18 + 19 + 20
N2 = 40
F + G = 28 + 29 + 30 + 31 + 32 + 33 + 34 + 35
I = (total value of imports in calculations supporting Table 3-12)
P2I = I * P2
E = (total value of exports in calculations supporting Table 3-12)
P1E = E * P1
B = 38 + 39 + 40 + 41 + 42 + 43 + 44 + 45 + 46 +47
GNP = from Gallman (1966)
P2 = from Great Britain 1860 evaluation
P1 = I20 (Table 3-14)
U = R + N + F + G + 36 - N2
fuel = 22 + 23 + 29 - 40

Table 3-14. United States 1870 emergy indices derived from Table 3-13.

Term	Name of Index	Expression[a]	Quantity	
I1	Renewable emergy	R	1527	E+20 sej/y
I2	Indigenous non-renewable emergy	N	704	E+20 sej/y
I3	Flow of imported emergy	F+G+36	281	E+20 sej/y
I4	Total emergy inflows	R+N+F+G+36	2512	E+20 sej/y
I5	Total emergy used, U	R+N+F+G+36-B-48	2510	E+20 sej/y
I6	Economic component	U-R	983	E+20 sej/y
I7	Total exported emergy	B+48	568	E+20 sej/y
I8	% Locally renewable	R/U * 100%	61	%
I9	Economic/environment ratio	(U-R)/R	0.64	
I10	Ratio of imports to exports	(F+G+36)/(B+48)	0.49	
I11	Ratio of exports to imports	(B+48)/(F+G+36)	2.0	
I12	Imports minus exports	(F+G+36)-(B+48)	-288	E+20 sej/y
I13	% of emergy use purchased	(F+G+36)/U *100%	11.2	%
I14	Fraction imported service	P2I/U	0.077	
I15	% of emergy use derived from home sources	(U-F-G-P2I)/U * 100%	88	%
I16	% of use that is free	(R+N0)/U	71	%
I17	Ratio of concentrated/rural	(F+G+36+N1)/(R+N0)	0.82	
I18	Empower density	U/(area)[b]	1.5E+11	sej/m^2
I19	Use per person	U/population[c]	6.5E+15	sej/person
I20	Ratio of use to GNP,	P1 = U/GNP	3.0E+13	sej/$
I21	Fraction Fossil Fuels	(fuel)/U	0.15	
I22	Fossil fuel use per person	fuel/population[c]	1.0E+15	sej/person

[a] Expressions refer to terms in Tables 3-12 and 3-13.
[b] 1870 farmed area = 1.65E+12 m^2 (from USCO (1874))
[c] 1870 population = 3.86E+07 people (USCO, 1874)

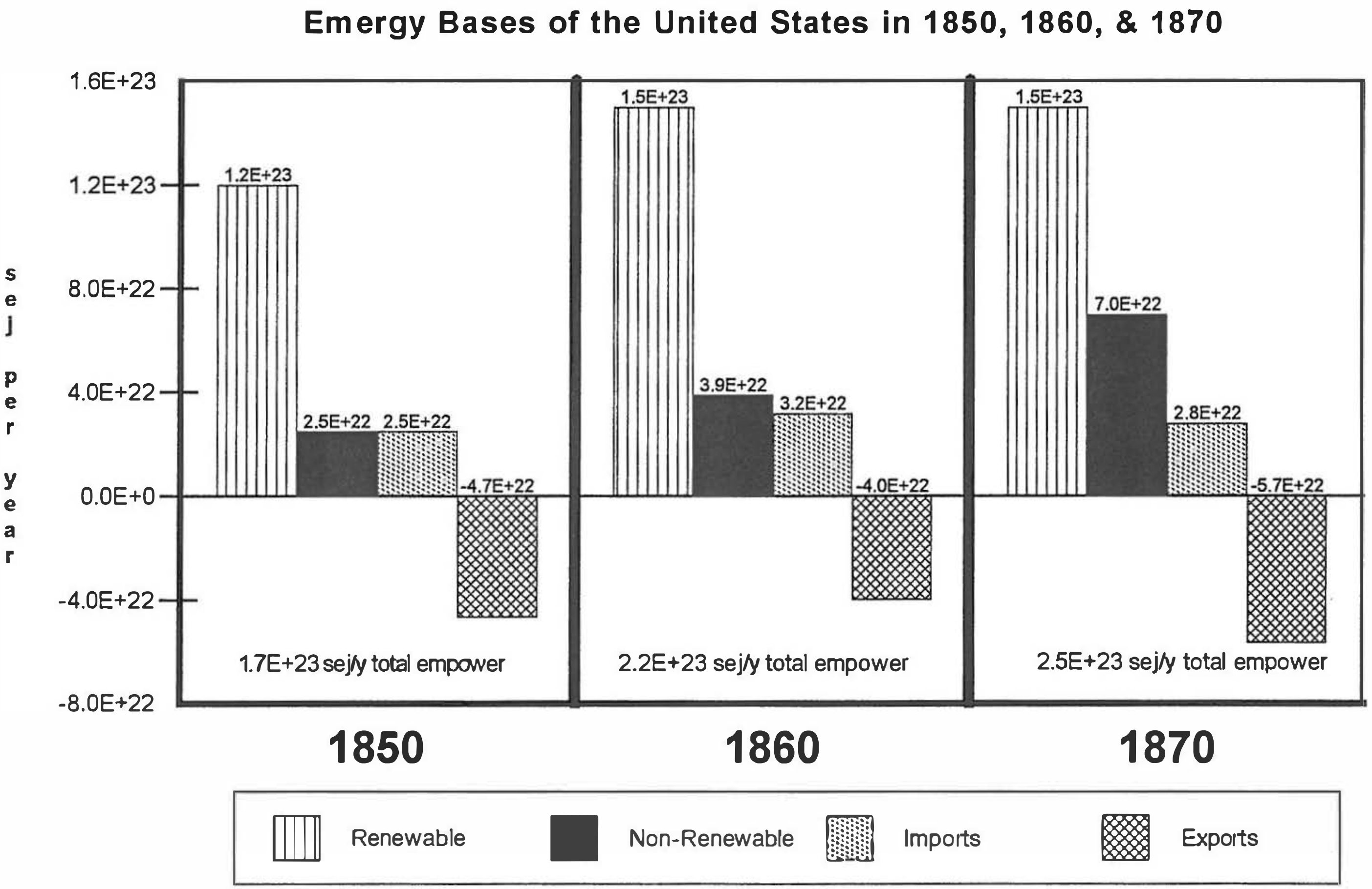


Figure 3-7. The renewable, non-renewable, import, and export emergy bases of the United States in 1850, 1860, and 1870.

4.2E+14 sej/person in 1860. The value increased significantly in 1870 to 1.0E+15 sej/person (terms I22, Tables 3-8, 3-11, and 3-14). Figure 3-7 gives a summarized comparison of the emergy bases for the U.S. in 1850, 1860, and 1870.

Emergy Evaluation of Great Britain in 1860

The results of the emergy evaluation of the Great Britain are given in Tables 3-15, 3-16, and 3-17. The emergy signature of the Great Britain in 1860 (including England, Scotland, Wales, and Ireland) is given in Table 3-15. The calculations in support of this signature are detailed in Appendix E. Table 3-16 gives a summary of several categories of related flows derived from the emergy signature. The primary renewable sources of emergy (R, Table 3-16) were rain, tide, and the earth cycle. The largest emergy import was services embodied in imports (term 26, Table 3-15), but this is more suggestive of the level of detail used in this evaluation than of the trading relationships of Great Britain. The major imports seem to have been raw materials, while large amounts of coal and iron products were exported (Table 3-15).

Table 3-17 gives several emergy indices derived from the summary flows. The empower density Great Britain in 1860 was calculated as 7.0E+11 sej/m^2, seven times higher than the 1860 U.S. value, 1.4E+11 (terms I18, Tables 3-16 and 3-11). The country's emergy-money ratio was calculated as 3.3E+14 sej/£, and the per capita emergy as 7.6E+15 sej/person (terms I20, and I19, Table 3-17). The U.S. emergy-money ratio in 1860 of 3.6E+14 sej/£ was slightly higher, while the per capita emergy use value was slightly lower (7.1E+15 sej/person). The annual per capita fossil fuel use of 2.3E+15 sej/person for Great Britain in 1860 was much greater than the 4.2E+14 sej/person value for the U.S. in 1860 (terms I22, Tables 3-17 and 3-11). An aggregated comparison of Great Britain and the U.S. in 1860 is given in Figure 3-8.

Table 3-15. Emergy evaluation of Great Britain in 1860.

Term	Item	Raw Units (J,£ or g)/y		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E20 sej/y)
RENEWABLE RESOURCES:					
1	Sunlight	1.1E+21	J	1	11
2	Wind, kinetic	2.9E+18	J	620	18
3	Rain, geopotential	2.0E+17	J	8900	18
4	Rain, chemical	1.9E+18	J	15000	291
5	Tide	9.6E+17	J	24000	232
6	Waves	1.0E+18	J	26000	260
7	Earth cycle	3.1E+17	J	29000	91
INDIGENOUS RENEWABLE ENERGY:					
	Not calculated in this evaluation				
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:					
8	Soil loss	8.7E+15	J	6.3E+04	5.5
9	Coal extraction	2.2E+18	J	3.3E+04	733
10	Iron	3.9E+12	g	1.0E+09	39
11	Copper ore	2.4E+11	g	4.5E+09	11
12	Tin ore	1.1E+10	g	2.0E+09	0.20
13	Lead ore	9.0E+10	g	4.5E+09	4.1
14	Zinc ore	4.4E+09	g	4.5E+09	0.20
IMPORTS AND OUTSIDE SOURCES:					
15	Plant products	9.0E+15	J	2.7E+04	2.4
16	Sugar & Molasses	6.7E+16	J	2.7E+04	18
17	Wood & wood products	2.1E+16	g	3.5E+04	7.4
17	Corn	5.2E+15	J	8.4E+04	4.4
18	Wheat	1.7E+16	J	8.4E+04	14
19	Cotton	7.4E+15	J	4.4E+05	33
20	Fisheries products	2.2E+14	J	2.0E+06	4.4
22	Animal Products	9.1E+14	J	2.0E+06	18
23	Iron & iron products	5.1E+10	g	7.6E+09	3.9
24	Brimstone, copper, tin, zinc, lead, & their products	1.4E+11	g	3.7E+09	5.2
25	Services embodied in imports	2.1E+08	£	3.6E+14	760
EXPORTS:					
26	Coal export	2.1E+17	J	3.3E+04	68
27	Other animal products	2.5E+14	J	1.4E+06	3.6
28	Fisheries products	6.5E+14	J	2.0E+06	13
29	Iron & steel	6.8E+10	g	7.6E+09	5.2
30	Services embodied in exports	1.6E+08	£	3.3E+14	542
31	Net emigration	1.3E+05	people	1.2E+17	157

Calculations in support of Table 3-15 are given in Appendix E.

Table 3-16. Summary of 1860 Great Britain annual empower and money flows from Table 3-15.

Term	Item	Solar Emergy (E20 sej/y)	Pounds E+07 £	sej/£
R	Renewable Sources (rain, tide, earth cycle)	613		
N	Nonrenewable Sources from within Great Britain	793		
N0	Dispersed Rural Sources	5.5		
N2	Emergy Exported without Use	68		
F + G	Imported Fuels, Minerals & Goods	102		
I	Pounds Paid for Imports		21	
P2I	Emergy Value of Service in Imports	760		
E	Pounds Received for Exports		16	
P1E	Emergy Value of Service in Exports	542		
B	Emergy of Exports	70		
GNP	Great Britain Domestic Product (1860)		67	
P2	World Emergy-Money Ratio, used in imports			3.6E+14
P1	Great Britain (1860) Emergy-Money Ratio			3.3E+14
U	Total Emergy Use	2199		
fuel	Emergy of Fossil Fuel Use	670		

Term Derivations (numbers refer to terms in Table 3-15):

term:
R = 4 + 5 + 7
N = 8 + 9 + 10 + 11 + 12 + 13 +14
N2 = 26
F + G = 15 + 16 + 17 + 18 + 19 + 20 + 21 + 22 + 23 + 24
I = (total value of imports in calculations supporting Table 3-15)
P2I = I * P2
E = (total value of exports in calculations supporting Table 3-15)
P1E = E * P1
B = 26 + 27 + 28 + 29
GNP = from Deane and Cole (1967)
P2 = from United States 1860 evaluation
P1 = 120 (Table 3-17)
U = R + N + F + G + 25 - N2
fuel = 9 - 26

Table 3-17. Great Britain 1860 emergy indices derived from Table 3-16.

Term	Name of Index	Expression[a]	Quantity	
I1	Renewable emergy	R	613	E+20 sej/y
I2	Indigenous non-renewable emergy	N	793	E+20 sej/y
I3	Flow of imported emergy	F+G+25	776	E+20 sej/y
I4	Total emergy inflows	R+N+F+G+25	2267	E+20 sej/y
I5	Total emergy used, (U)	R+N+F+G+P2I-B-30	2199	E+20 sej/y
I6	Economic component	U-R	1586	E+20 sej/y
I7	Total exported emergy	B+30	631	E+20 sej/y
I8	% Locally renewable	R/U *100%	28	%
I9	Economic/environment ratio	(U-R)/R	2.6	
I10	Ratio of imports to exports	(F+G+25)/(B+30)	1.4	
I11	Ratio of exports to imports	(B+30)/(F+G+25)	0.70	
I12	Imports minus exports	(F+G+25)-(B+30)	230	E+20 sej/y
I13	% of emergy use purchased	(F+G+25)/U *100%	39	%
I14	Fraction imported service	P2I/U	0.35	
I15	% of emergy use derived from home sources	(U-F-G-25)/U * 100%	61	%
I16	% of use that is free	(R+N0)/U	28	%
I18	Empower density	U/(area)[b]	7.0E+11	sej/m^2
I19	Use per person	U/population[c]	7.6E+15	sej/person
I20	Ratio of use to GNP,	P1 = U/GNP	3.3E+14	sej/£
I21	Fraction Fossil Fuels	(fuel)/U	0.30	
I22	Fossil fuel use per person	fuel/population[c]	2.3E+15	sej/person

[a] Expressions refer to terms in Tables 3-15 and 3-16.

[b] 1860 area = 3.13E+11 m^2 (estimated from UKCSO (1992))

[c] 1860 population = 2.88E+07 people (Mitchell, 1988)

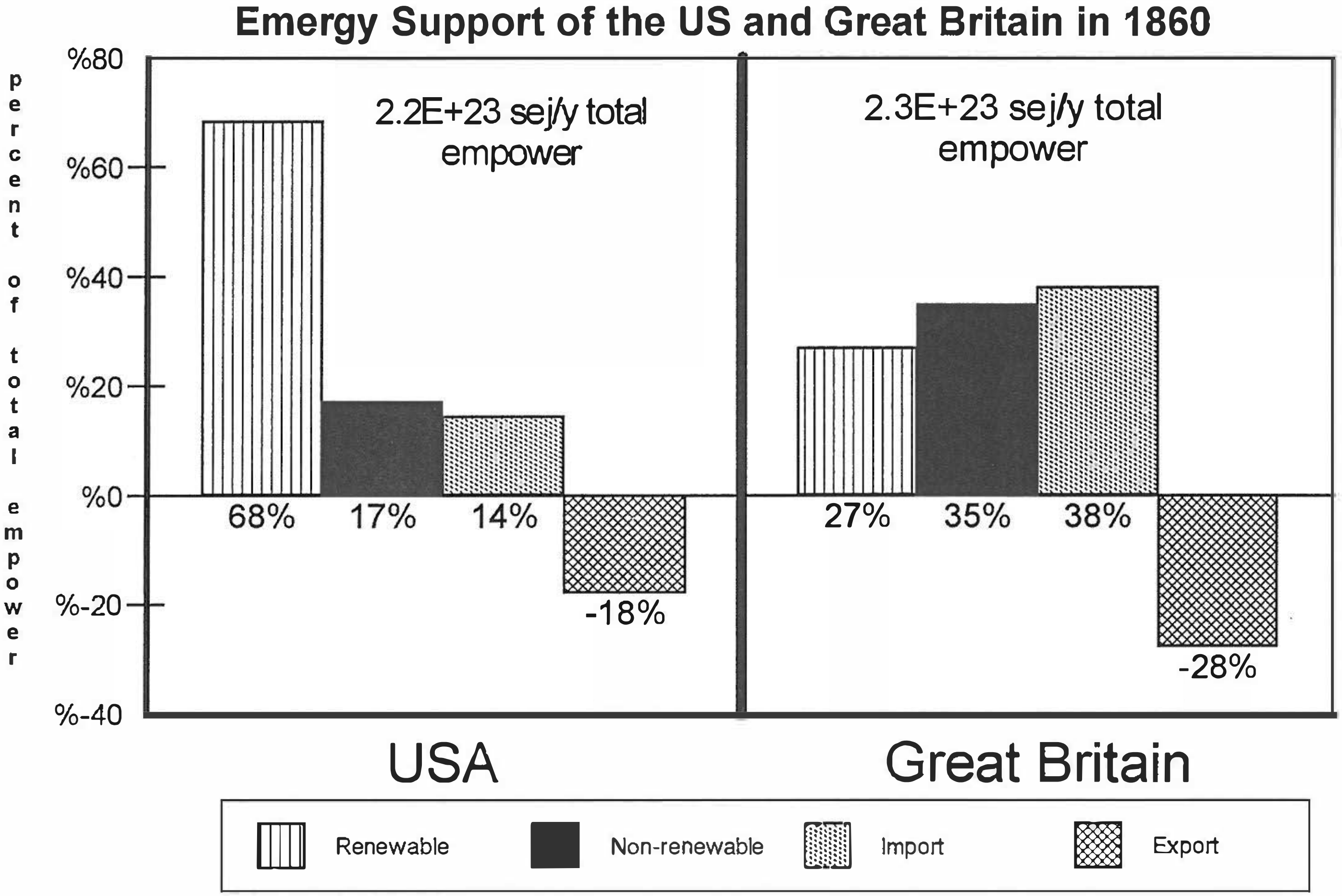


Figure 3-8. The renewable, non-renewable, import, and export emergy support of the United States and Great Britain in 1860.

Emergy Evaluation of the United States Slave System

The model of the United States slavery system used to calculate the transformity of slave labor is diagrammed in Figure 3-9. The calculations of slave labor transformity are given in Table 3-18. The transformity of U.S. slave plantation labor was calculated to be 3.3E+13 sej/labor-day or 9.0E+15 sej/labor-year (terms 11 and 12, Table 3-18). Free environmental support, pork for food, and manufactures (for personal use and as agricultural tools) were the largest emergy contributors to slave labor at 36%, 23%, and 17% of the emergy input respectively. The transformity of slave labor (9.0E+15 sej/labor-year) was higher than the per capita emergy use for the U.S. as a whole in 1860 (7.1E+15 sej/person-y, I19, Table 3-11). The subjectivity of determining the environmental support for slave labor (term 1, Table 3-18) minimized the significance of this difference though.

Emergy Evaluations of the Confederate States

The results of the emergy evaluation of the Confederate states in 1860 are given in Tables 3-19, 3-20, and 3-21. Evaluations were performed on the Confederate states for the years 1861, 1862, 1863, and 1864. Where these evaluations differ from the 1860 evaluation, the results are presented in Table 3-22. The Confederate states were taken to be the succeeding states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia (excluding West Virginia where possible) (Figure 1-3).

The imports of the Confederate states in 1860 were dominated by food and finished goods (Table 3-19; Fishlow, 1964). This evaluation accounts for imports of finished goods from the Union states only in terms of the estimated human services embodied within these goods. Human services in imports from the North (term 37, Table 3-19) is large because of human services in finished goods. The primary source of imported food was the midwestern Union states. Cotton, naval stores, and lumber were the primary exports from the Confederate states (USTD, 1862;

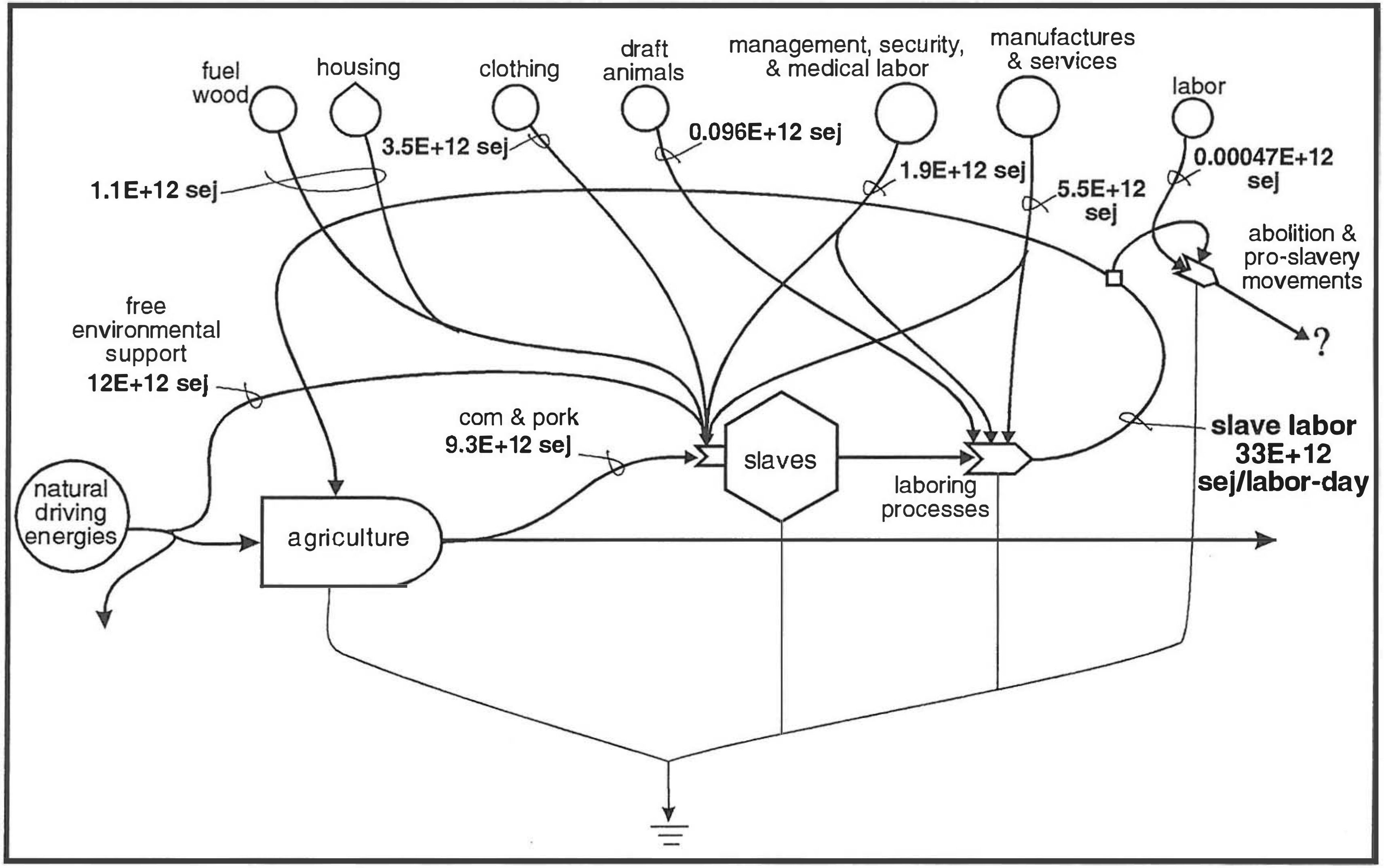


Figure 3-9. A model of the United States plantation slavery system circa 1850-1860. Flows are given in sej per day of slave labor.

Table 3-18. An emergy evaluation of United States slave plantation agriculture circa 1850 - 1860.

Term	Item	Raw Units (unit/labor-day)		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E12 sej/labor-day)
	Inputs				
1	free environmental support	3.7E+02	m^2	3.2E+10	12
2	wood	3.0E+07	J	3.5E+04	1.1
3	corn	1.9E+07	J	8.4E+04	1.6
4	pork	7.8E+06	J	1.0E+06	7.7
5	cotton clothing	4.4E+05	J	*1.9E+06*	0.84
6	wool clothing	7.0E+05	J	*3.8E+06*	2.7
7	draft animals	9.6E+05	J	1.0E+05	0.096
8	management & security labor	7.0E-02	labor-d	2.6E+13	1.9
9	manufactures	0.10	$	7.4E+13	5.5
	Transformity of Slave Labor = 3.3E+13 sej/labor-day (sum of 1 - 9)				
	Additional Costs				
10	abolition & pro-slavery movements	1.8E-05	labor-d	2.6E+13	0.00047
11	**Transformity of Slave Labor = 3.3E+13 sej/labor-day** (sum of 1 - 10)				
12	**Transformity of Slave Labor = 9.0E+15 sej/person-y**				

Calculations in support of Table 3-18.

Term:

1 Free Environmental Empower Support

per-capita land area support = 1.0E+05 m^2 (assumed as 1/10 ha/person-y)

labor days per year = 270 days/person-y (from Fogel & Engerman (1974))

area / labor-d output = 3.7E+02 m^2/labor-d

2 Wood Fuel & Building Material

per-capita wood in quarters = 5.5E+08 J/y (estimated from Fogel and Engerman (1974))

per-capita fuelwood use= 7.6E+09 J/y (estimated from Steer (1948))

labor days per year = 270 days/person-y (from Fogel & Engerman (1974))

wood / labor-d output = 3.0E+07 J wood / labor-d

Fuelwood use is estimated as 10% of the U.S. per-capita fuelwood use (calculated from USDC (1975)).

3 Corn

annual per-capita consumption = 5.0E+09 J/person-y (estimated from Fogel & Engerman (1974))

labor days per year = 270 days/person-y (from Fogel & Engerman (1974))

Fogel and Engerman estimate 78% of grain consumption by slaves as corn. This calculation assumes that 100% of the total grain consumption estimate is corn.

4 Pork

annual per-capita consumption = 2.1E+09 J/person-y (estimated from Fogel & Engerman (1974))

labor days per year = 270 days/person-y (from Fogel & Engerman (1974))

consumption / labor-d output = 7.8E+06 J pork / labor-d

Fogel and Engerman estimate 75% of slave animal product consumption as pork. This calculation assumes 100% of the estimate is pork.

Table 3-18 continued.

5 Cotton Clothing
per-capita cotton clothing issue = 1.2E+08 J/y (estimated from Fogel and Engerman (1974))
labor days per year = 270 days/person-y (from Fogel & Engerman (1974))
issue / labor-d output = 4.4E+05 J clothing / labor-d
Fogel and Engerman's estimates of clothing issue is used with assumed weights for clothing.
The transformity is for modern cotton from Odum et al. (1987b).

6 Wool Clothing
per-capita cotton clothing issue = 1.9E+08 J/y (estimated from Fogel and Engerman (1974))
labor days per year = 270 days/person-y (from Fogel & Engerman (1974))
issue / labor-d output = 7.0E+05 J clothing / labor-d
Fogel and Engerman's estimates of clothing issue is used with assumed weights for clothing.
The transformity is for modern wool from Odum et al. (1987b).

7 Draft Animals
per-capita draft animal use = 431 animal-hr/slave-y (estimated from Grossman (1992))
hourly animal output = 6.0E+05 J/animal-h (estimated from Sundberg et al. (1994a))
labor days per year = 270 days/person-y (from Fogel & Engerman (1974))
animal input / labor-d output = 9.6E+05 J / labor-d
This calculation assumes the draft animals work 8 hour days for half of the 270 days/year slaves work.
Transformity is from Sundberg et al. (1994a) for 17th-century Swedish horses.

8 Management & Security Labor
management & security labor = 12.3 labor-y/labor-y (estimated from Conrad & Myer (1958))
plantation owner ,etc. labor = 5.2 labor-y/labor-d (estimated from Synder (1933))
medical labor = 1.43 labor-y/labor-d (estimated from Synder (1933))
labor days per year = 270 days/person-y (from Fogel & Engerman (1974))
labor-d input / labor-d output = 7.0E-02 labor-d / labor-d

9 Manufactures & Machinery
per-capita purchase of = 20.0 $/y (from Synder (1933))
labor days per year = 270 days/person-y (from Fogel & Engerman (1974))
purchase / labor-d output = 0.07 $ manufactures / labor-d
The emergy-money ratio is from the U.S. 1860 evaluation.

10 Abolition & Pro-slavery Movements
management & security labor = 4.8E-03 labor-y/labor-y (assumed from Manning (1992), and Fogel & Engerman (1974))
labor days per year = 270 days/person-y (from Fogel & Engerman (1974))
labor-d input / labor-d output = 1.8E-05 labor-d / labor-d
This calculation estimates the emergy input to the abolition movement from the amount of emergy Great Britain was willing to invest in preventing the slave trade from 1810 to 1870. The emergy per slave is calculated by dividing the Great Britain investment by the number of slaves traded during the corresponding period, roughly a willingness-to-pay method using emergy. The transformity of labor is from the Great Britain 1860 evaluation.

11 Calculated assuming a 270 day labor-year.

12 Calculated assuming a 270 day labor-year.

Table 3-19. Emergy evaluation of the Confederate states in 1860.

Term	Item	Raw Units (J,$ or g)/y	Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E20 sej/y)
RENEWABLE RESOURCES:				
1	Sunlight	2.6E+21 J	1	26.2
2	Wind, kinetic	9.5E+18 J	620	58.7
3	Rain, geopotential	3.0E+18 J	8900	271.0
4	Rain, chemical	2.9E+18 J	15000	428.9
5	Tide	3.6E+17 J	24000	85.5
6	Waves	1.5E+18 J	26000	400.2
7	Earth cycle	8.1E+17 J	29000	235.1
INDIGENOUS RENEWABLE ENERGY:				
8	Forest extraction	5.5E+16 J	8000	4.4
9	Fuelwood use	6.6E+17 J	8000	52.5
10	Hydro-power	1.9E+15 J	8900	0.17
11	Plant leaf & fiber products	1.6E+16 J	27000	4.2
12	Breadstuffs & grains	1.2E+17 J	27000	31.6
13	Fruit & root crops	2.5E+15 J	27000	0.69
14	Ginned cotton	1.4E+16 J	27000	3.8
15	Sugar & molasses	1.0E+16 J	27000	2.8
16	Shellfish fisheries	1.4E+13 J	8.0E+05	0.113
17	Butter & cheese	6.9E+14 J	1.3E+06	8.9
18	Finfish fisheries	5.1E+12 J	2.0E+06	0.1
19	Livestock production	3.1E+15 J	2.0E+06	61.7
20	Wool	7.1E+13 J	3.8E+06	2.7
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:				
21	Soil loss	1.1E+17 J	6.3E+04	66.7
22	Coal	1.8E+16 J	3.3E+04	6.0
23	Iron ore	6.7E+10 g	1.0E+09	0.67
24	Copper	6.0E+09 g	4.5E+09	0.27
25	Lead	7.2E+08 g	4.5E+09	0.033
IMPORTS AND OUTSIDE SOURCES:				
26	Sugar, fruits, & other plant products	8.8E+14 J	2.7E+04	0.24
27	Grains & breadstuffs	7.1E+14 J	8.5E+04	0.607
28	Animal products	7.6E+13 J	1.0E+06	0.777
29	Plant derived ash & soda	7.8E+10 g	2.2E+08	0.062
30	Iron & iron products	7.8E+10 g	2.3E+09	1.8
31	Lead & lead products	2.1E+07 g	8.5E+09	0.0018
32	Gold coin	6.1E+05 g	4.4E+14	2.7
33	Silver coin	2.8E+07 g	6.5E+12	1.8
34	Additional services in foreign imports	2.7E+07 $	6.7E+13	18.
35	Human services in imports from USA	2.5E+08 $	7.5E+13	187.
EXPORTS:				
36	Grains, breadstuffs, & other plant products	9.1E+14 J	7.1E+04	0.65
37	Wood & wood products	4.2E+16 J	3.5E+04	15.
38	Coal	3.8E+13 J	3.3E+04	0.013
39	Cotton	2.0E+16 J	4.4E+05	89.4
40	Other animal products	7.7E+13 J	1.0E+06	0.76
41	Iron & iron products	4.6E+07 g	7.5E+09	0.0035
42	Gold & silver coin & bullion	3.1E+05 g	2.2E+14	0.68
43	Additional services in foreign exports	8.2E+07 $	1.0E+14	84.7
44	Human services in exports to USA	9.0E+07 $	1.0E+14	92.9

Calculations in support of Table 3-19 are given in Appendix F.

Table 3-20. Summary of 1860 Confederate states annual empower and money flows from Table 3-19.

Term	Item	Solar Emergy (E20 sej/y)	Dollars E+07 $	sej/$
R	Renewable sources (rain, tide)	750		
N	Nonrenewable sources flow w/in Country	74		
N0	Dispersed Rural Source	67		
N1	Concentrated Use	182		
N2	Exported without Use	0		
F +G	Imported Fuels, Minerals & Goods	8		
I	Dollars Paid for Imports		28	
P2I	Emergy Value of Service in Imports	206		
E	Dollars Received for Exports		35	
P1E	Emergy Value of Service in Exports	363		
B	Exports	106		
GNP	Gross National Product (1860)		100	
P2	World emergy/money ratio, used in imports			6.7E+13
P1	Country's Emergy/money ratio			1.0E+14
U	Total system emergy use	1037		
fuel	Emergy of fossil fuel use	6		

Term Derivations (numbers refer to terms in Table 3-19):

term:
R = 4 + 5 + 7
N = 21 + 22 + 23 + 24 + 25
N1 = 8 + 9 + 10 + 11 + 12 + 13 + 14 + 15 + 16 + 17 + 18 + 19 + 20
N2 = no exports without use
F + G = 26 + 27 + 28 + 29 + 30 + 31 + 32 + 33
I = (total value of imports in calculations supporting Table 3-19)
P2I = I * P2
E = (total value of exports in calculations supporting Table 3-19)
P1E = E * P1
B = 36 + 37 + 38 + 39 + 40 + 41 + 42
GNP = As used by Fishlow (1964) (1/3 of 1860 USA GNP)
P2 = from Great Britain 1860 evaluation
P1 = I20 (Table 3-21)
U = R + N + F + G + 34 + 35 - N2
fuel = 22 - 38

Table 3-21. Confederate states 1860 emergy indices derived from Table 3-20.

Term	Name of Index	Expression[a]	Quantity	
I1	Renewable emergy	R	750	E+20 sej/y
I2	Indigenous non-renewable emergy	N	74	E+20 sej/y
I3	Flow of imported emergy	F+G+34+35	214	E+20 sej/y
I4	Total emergy inflows	R+N+F+G+34+35	1145	E+20 sej/y
I5	Total human system emergy, U	R+N+F+G+34+35-N2	1037	E+20 sej/y
I6	Economic component	U-R	287	E+20 sej/y
I7	Total exported emergy	B+43+44	284	E+20 sej/y
I8	% Locally renewable	R/U * 100%	72	%
I9	Economic/environment ratio	(U-R)/R	0.38	
I10	Ratio of imports to exports	(F+G+34+35)/(B+43+44)	0.8	
I11	Ratio of exports to imports	(B+43+44)/(F+G+34+35)	1.3	
I12	Imports minus exports	(F+G+34+35)-(B+43+44)	-70	E+20 sej/y
I13	% of emergy use purchased	(F+G+34+35)/U *100%	20.6	%
I14	Fraction imported service	P2I/U	0.20	
I15	% of emergy use derived from home sources	(U-(F+G+34+35))/U * 100%	79	%
I16	% of use that is free	(R+N0)/U	79	%
I17	Ratio of concentrated/rural	(F+G+34+35+N1)/(R+N0)	0.49	
I18	Empower density	U/(area)[b]	1.4E+11	sej/m^2
I19	Use per person	U/(population)[c]	1.2E+16	sej/person
I20	Ratio of use to GNP,	P1=U/GNP	1.0E+14	sej/$
I21	Fraction fossil fuels & minerals	(fuel)/U	0.0058	
I22	Fossil fuel use per person	(fuel)/(population)[c]	6.8E+13	sej/person

[a] Expressions refer to terms in Tables 3-19 and 3-20.
[b] 1860 area = 7.37E+11 m^2 (from USCO (1864))
[c] 1860 population = 8.73E+06 people (from USCO (1864))

Table 3-22. Significant changes in the emergy evaluation of the Confederate states from 1861 through 1865. This table is an index of change only and can not be summed for national evaluation without double counting. Term designations are the same as those in Table 3-19.

Term	Item	1860	1861	1862	1863	1864	Total 1861-1865
				Units are 1E+20 sej or sej/y			
12	Breadstuffs & grains	31.6	21.1	18.8	22.8		
13	Fruit & root crops	0.68	0.78	0.62	0.94		
14	Cotton	3.78	3.19	1.06	0.35	0.21	
15	Sugar & molasses	2.75				0.015	
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:							
23	Iron	0.67				total extraction =	0.35
						emergy value of refined iron =	*3.72*
24	Copper	0.27				total extraction through 9/30/1864 =	0.016
						emergy value of refined copper =	*0.15*
25	Lead	0.033				total extraction =	0.073
						emergy value of refined lead =	*0.13*
IMPORTS AND OUTSIDE SOURCES:							
28	Animal products	0.77				total import through the blockade =	146
30	Iron & iron products	1.80				total import through the blockade =	0.044
30b	Saltpeter	negligible				total import through the blockade =	0.032
31	Lead	0.0018				total import through the blockade =	0.115
34a	Total services in foreign imports	301				total import through the blockade =	2.60
35a	Total services in Union imports	317				difficult to accurately estimate	
EXPORTS:							
39	Cotton	89				total export through the blockade =	4.63
43a	Total services in exports	396				total export through the blockade =	12.8
44a	Services in exports to Union	101				difficult to accurately estimate	

Calculations in support of Table 3-22 are given in Appendix G.

Fishlow, 1964), though large amounts of foodstuffs imported from the midwestern Union states were exported through New Orleans (Fishlow, 1964). The existence of these exports was evident in the large emergy value of raw cotton and animal products exported from the Confederate states (terms 39 and 40, Table 3-19).

Summary indices calculated for the Confederate states are given in Table 3-21. The 1.4E+11 sej/m^2 annual empower density of the Confederate states was identical to that of the U.S. as a whole (terms I18, Tables 3-21 and 3-11). At 1.2E+16 sej/person and 1.0E+14 sej/\$, the per capita emergy use and emergy-money ratio for the Confederate states were larger than the 7.1E+15 sej/person and 7.4E+13 sej/\$ values for the U.S. as a whole (terms I19 and I20, Tables 3-21 and 3-11). Most significantly, the emergy of per capita fossil fuel use in the Confederate states was much lower than that in the U.S. as a whole at 6.8E+13 sej/person verses 4.2E+14 sej/person (terms I22, Tables 3-21 and 3-11).

Table 3-22 details changes in the emergy basis of the Confederate states during the Civil War and showed a significant decline in imports and exports as well as in cotton and sugar production. The production of breadstuffs and grains also declined over the period of the War. This evaluation did not detail the progressive loss of free environmental support as: 1.) Confederate territory was captured and controlled by the Union; and 2.) railroads and other means of transportation were destroyed, effectively isolating large areas of Confederate controlled territory from the larger Confederate system.

Emergy Evaluations of the Union States

The results of the emergy evaluation of the Union states in 1860 are given in Tables 3-23, 3-24, and 3-25. As with the Confederate states, evaluations were performed on the Union states for the years 1862, 1862, 1863, and 1865. Where these evaluations differ from the 1860 evaluation, the results are presented in Table 3-26. The Union states were taken to be the loyal states and territories: California, Connecticut, Delaware, Kentucky, Illinois, Indiana, Iowa, Maine,

Table 3-23. Emergy evaluation of the Federal or Union states in 1860.

Term	Item	Raw Units (J,$ or g)/y		Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E20 sej/y)
RENEWABLE RESOURCES:					
1	Sunlight	2.9E+21	J	1	29.4
2	Wind, kinetic	1.8E+19	J	620	109.1
3	Rain, geopotential	3.8E+18	J	8900	335.7
4	Rain, chemical	3.0E+18	J	15000	444.0
5	Tide	1.8E+17	J	24000	42.7
6	Waves	1.5E+18	J	26000	400.4
7	Earth cycle	1.0E+18	J	29000	291.2
INDIGENOUS RENEWABLE ENERGY:					
8	Forest extraction	1.4E+17	J	8000	11.5
9	Fuelwood Use	1.7E+18	J	8000	136.5
10	Hydro-power	1.9E+16	J	8900	1.7
11	Plant leaf & fiber products	2.4E+17	J	27000	64.3
12	Breadstuffs & grains	1.9E+17	J	27000	51.5
13	Fruit & root crops	6.2E+15	J	27000	1.7
14	Ginned cotton	1.2E+14	J	27000	0.033
15	Sugar & molasses	5.0E+14	J	27000	0.13
16	Shellfish fisheries	2.1E+13	J	8.0E+05	0.17
17	Butter & cheese	5.7E+15	J	1.3E+06	74.5
18	Finfish fisheries	4.5E+13	J	2.0E+06	0.91
19	Livestock production	5.1E+15	J	2.0E+06	101.9
20	Wool	4.3E+14	J	3.8E+06	16.4
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:					
21	Soil loss	2.6E+17	J	6.3E+04	162.3
22	Coal extraction	3.7E+17	J	3.3E+04	123.2
23	Crude petroleum	3.1E+15	J	5.3E+04	1.6
24	Iron	2.4E+12	g	1.0E+09	24.4
25	Copper	8.6E+09	g	4.5E+09	0.39
26	Nickelore	2.4E+09	g	4.5E+09	0.11
27	Lead	1.1E+10	g	4.5E+09	0.49
28	Zinc	1.2E+10	g	4.5E+09	0.54
29	Quicksilver (Hg)	1.0E+08	g	1.0E+09	0.00102
30	Silver	3.6E+06	g	5.0E+09	0.00018
31	Gold	6.9E+07	g	5.0E+09	0.00346
IMPORTS AND OUTSIDE SOURCES:					
32	Sugar, fruits, & other plant products	7.1E+15	J	2.7E+04	1.9
33	Coal	6.7E+15	J	3.3E+04	2.2
34	Cotton	3.1E+15	J	4.4E+05	13.8
35	Fisheries & fish oils	2.2E+13	J	2.0E+06	0.45
36	Whale oil & bone	1.3E+14	J	3.6E+07	47.
37	Plant derived ash & soda	4.9E+10	g	2.2E+08	0.11
38	Iron & iron products	2.9E+11	g	7.6E+09	21.7
39	Lead, chalk, brimstone, & their products	4.4E+10	g	4.3E+09	1.9
40	Silver coin	6.9E+07	g	6.5E+12	4.5
41	Gold coin	1.5E+06	g	4.4E+14	6.6
42	Additional services in foreign imports	3.2E+08	$	6.7E+13	214
43	Human services in imports from CSA	9.0E+07	$	1.0E+14	92.9
44	Net immigration	1.5E+05	people	1.2E+17	183
EXPORTS:					
45	Grains, breadstuffs, & other plant products	5.8E+15	J	7.9E+04	4.6
46	Wood & wood products	4.8E+16	J	3.5E+04	16.7
47	Coal	5.2E+14	J	3.3E+04	1.7
48	Cotton	6.0E+14	J	4.4E+05	2.6
49	Other animal products	7.7E+14	J	1.5E+06	14
50	Fisheries products	3.1E+14	J	2.0E+06	6.2
51	Whale products	5.1E+13	J	3.6E+07	19.
52	Iron & iron products	8.3E+09	g	7.6E+09	0.63
53	Gold & silver coin & bullion	4.1E+07	g	2.2E+14	90.
54	Additional services in foreign exports	2.2E+08	$	7.5E+13	166.5
55	Human services in exports to CSA	2.6E+08	$	7.5E+13	192.

Calculations in support of Table 3-23 are given in Appendix H.

Table 3-24. Summary of 1861 Federal states annual empower and money flows from Table 3-23.

Term	Item	Solar Emergy (E20 sej/y)	Dollars E+07 $	sej/$
R	Renewable sources (rain, tide)	778		
N	Nonrenewable sources flow w/in Country	313		
N0	Dispersed Rural Source	162.3		
N1	Concentrated Use	772		
N2	Exported without Use	2		
F + G	Imported Fuels, Minerals & Goods	101		
I	Dollars Paid for Imports		42	
P2I	Emergy Value of Service in Imports	317		
E	Dollars Received for Exports		59	
P1E	Emergy Value of Service in Exports	442		
B	Exports	154		
GNP	Gross National Product (1860)		200	
P2	World emergy/money ratio, used in imports			6.7E+13
P1	Country's Emergy/money ratio			7.5E+13
U	Total system emergy use	1496		
fuel	Emergy of fossil fuel use	125		

Term Derivations (numbers refer to terms in Table 3-23):

term:
R = 4 + 5 + 7
N = 21 + 22 + 23 + 24 + 25 + 26 + 27 + 28 + 29 + 30 + 31
N1 = 8 + 9 + 10 + 11 + 12 + 13 + 14 + 15 + 16 + 17 + 18 + 19 + 20
N2 = from USA 1860 evaluation
F + G = 32 + 33 + 34 + 36 + 33 + 34 + 35 + 36 + 37 + 38 + 39 + 40 + 41
I = (total value of imports in calculations supporting Table 3-23)
P2I = I * P2
E = (total value of exports in calculations supporting Table 3-23)
P1E = E * P1
B = 45 + 46 + 47 + 48 + 49 + 50 + 51 + 52 + 53
GNP = As used by Fishlow (1964) (2/3 of 1860 USA GNP)
P2 = from Great Britain 1860 evaluation
P1 = I20 (Table 3-25)
U = R + N + F + G + 42 + 43 - N2
fuel = 22 + 23 + 33 - 47

Table 3-25. Federal states 1860 emergy indices derived from Table 3-24.

Term	Name of Index	Expression[a]	Quantity	
I1	Renewable emergy	R	778	E+20 sej/y
I2	Indigenous non-renewable emergy	N	313	E+20 sej/y
I3	Flow of imported emergy	F+G+P2I	407	E+20 sej/y
I4	Total emergy inflows	R+N+F+G+42+43	1957	E+20 sej/y
I5	Total human system emergy, U	R+N+F+G+42+43-N2	1496	E+20 sej/y
I6	Economic component	U-R	718	E+20 sej/y
I7	Total exported emergy	B+54+55	596	E+20 sej/y
I8	% Locally renewable	R/U *100%	52	%
I9	Economic/environment ratio	(U-R)/R	0.92	
I10	Ratio of imports to exports	(F+G+42+43)/(B+54+55)	0.68	
I11	Ratio of exports to imports	(B+54+55)/(F+G+42+43)	1.5	
I12	Imports minus exports	(F+G+42+43)-(B+54+55)	-189	E+20 sej/y
I13	% of emergy use purchased	(F+G+42+43)/U *100%	27.2	%
I14	Fraction imported service	P2I/U	0.21	
I15	% of emergy use derived from home sources	(U-(F+G+42+43))/U * 100%	72	%
I16	% of use that is free	(R+N0)/U	63	%
I17	Ratio of concentrated/rural	(F+G+42+43+N1)/(R+N0)	1.3	
I18	Empower density	U/(area)[b]	1.6E+11	sej/m^2
I19	Use per person	U/(population)[c]	7.5E+15	sej/person
I20	Ratio of use to GNP,	P1=U/GNP	7.5E+13	sej/$
I21	Fraction Fossil Fuels & Minerals	(fuel)/U	0.083	
I22	Fossil fuel use per person	(fuel)/(population)[c]	5.5E+14	sej/person

[a] Expressions refer to terms in Tables 3-24 and 3-23.

[b] 1860 area = 1.51E+12 m^2 (from USCO (1864))

[c] 1860 population = 2.27E+07 people (from USCO (1864))

Table 3-26. Significant changes in the emergy evaluation of the Federal states from 1862 through 1865. This table is an index of change only and can not be summed for national evaluation without double counting. Term designations are the same as those in Table 3-23.

				Year:		
		1860	1862	1863	1864	1865
Term	Item	Units are in flows of 1E+20 sej/year				
11	Plant leaf & fiber products	64	75	65	64	84
12	Breadstuffs & grains	52	52	44	43	63
12a	*emergy value of harvested product*	*162*	*163*	*138*	*132*	*196*
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:						
23	Crude petroleum	1.62	9.88	8.44	6.84	8.08
30	Silver	0.00018	0.0054	0.0102	0.0132	0.0135
30a	*emergy value of refined product*	*0.23*	*7.04*	*13.29*	*17.20*	*17.59*
IMPORTS AND OUTSIDE SOURCES:						
34	Cotton, raw	11.19	0.86	0.98	0.77	***
40	Silver coin	4.47	2.67	4.66	2.17	0.88
41	Gold coin	6.64	58	17	40	24
42	Services in foreign imports	225	150	181	240	178
43	Human services in Southern imports	93	n.a.	n.a.	n.a.	n.a.
44	Net immigration	183	140	244	271	351
EXPORTS:						
48	Cotton	2.64	0.0000017	0.0000018	0.0000021	0.0000016
53	Gold & silver coin & bullion	90	59	148	285	116
54	Human services in foreign exports	104	159	229	239	229
55	Human services in exports to CSA	192	n.a.	n.a.	n.a.	n.a.

Calculations in support of Table 3-26 are given in Appendix I.

Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Vermont, and Wisconsin (and including West Virginia where possible) (Figure 1-3).

The emergy signature of the Union states (Table 3-23) was similar to that of the U.S. as a whole (Table 3-9) with the exception of cotton import and export (terms 34 and 48, Table 3-23). Summary indices given in Table 3-25 show the Union states had an annual empower density (1.6E+11 sej/m^2 (term I18, Table 3-25)) roughly equal to that of the Confederate states (1.4E+11 sej/m^2 (term I18, Table 3-21)). The Union states' 7.5E+15 sej/person and 7.5E+13 sej/$ per capita emergy use and emergy-money ratio statistics were significantly smaller than the 1.2E+16 sej/person and 1.0E+14 sej/person statistics of the Confederate states (terms I19 and I 20, Tables 3-25 and 3-21). Both the Union states and the Confederate states evaluations were partly dependent upon the human services embodied in imports and exports between the two systems. The aggregated emergy bases of the Union and Confederate systems are shown in Figure 3-10. The emergy support of the Confederate states, Union states, and U.S. as a whole in 1860 is shown in Figure 3-11.

The changes in the emergy signature of the Union states over the course of the War detailed the increases in petroleum and silver extraction noted for the U.S. 1870 evaluation (terms 23, 30 and 30a, Table 3-26). Other trends were the decrease in cotton imports and exports over the course of the War (terms 34 and 48, Table 3-26). Overall, Table 3-26 suggested a much smaller effect of the War on the Union states compared to the effect on Confederate states detailed in Table 3-22.

Emergy Evaluations of the Civil War

The results of the emergy evaluation of the United States Civil War are given in Table 3-27. An energy circuit model of the U.S. Civil War, with the general categories of emergy from Table 3-27 labeled, is given in Figure 3-12. Labor and other human services (1.86E+23 sej

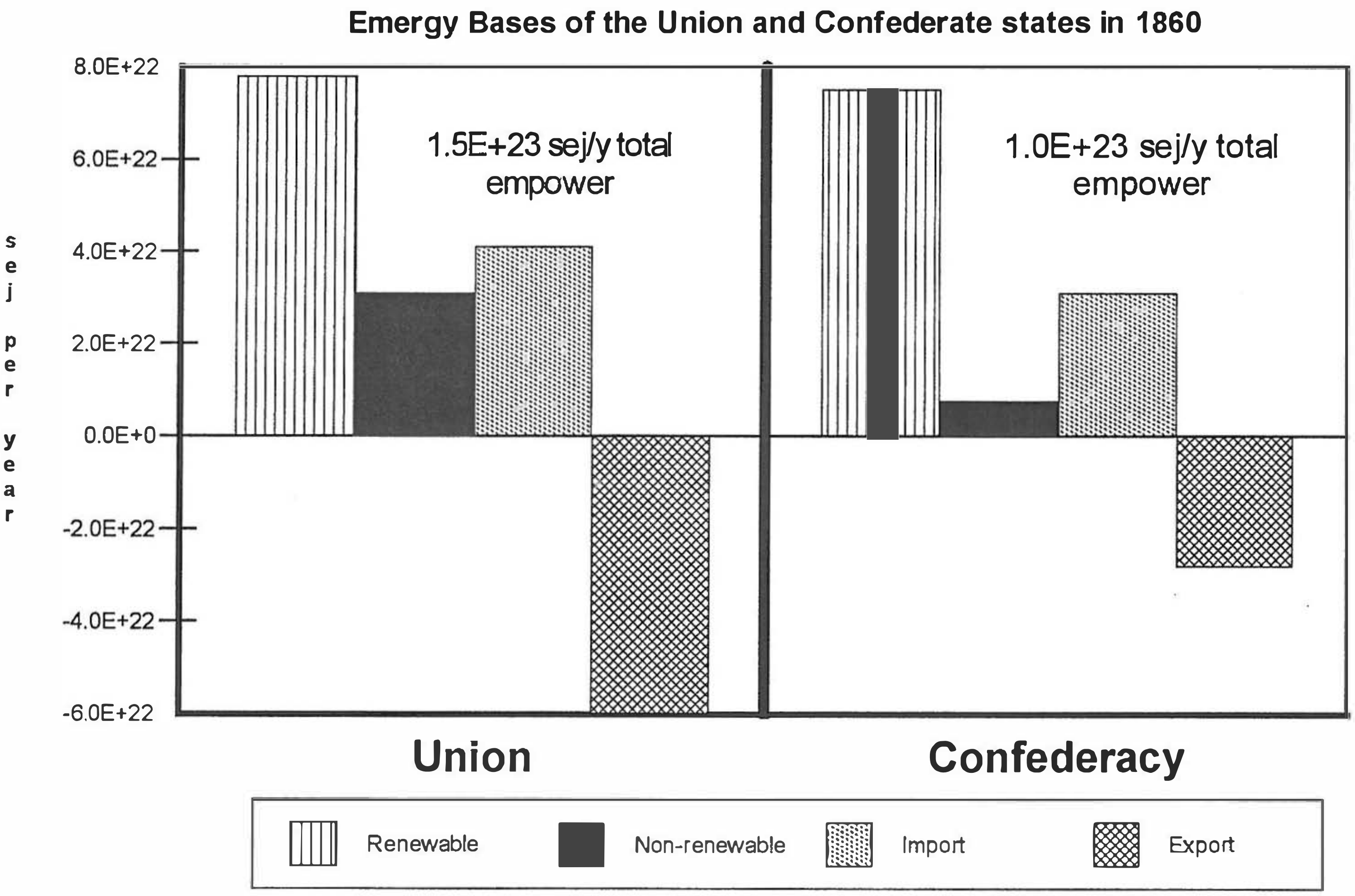


Figure 3-10. The renewable, non-renewable, import, and export emergy bases of the Union and Confederate states in 1860.

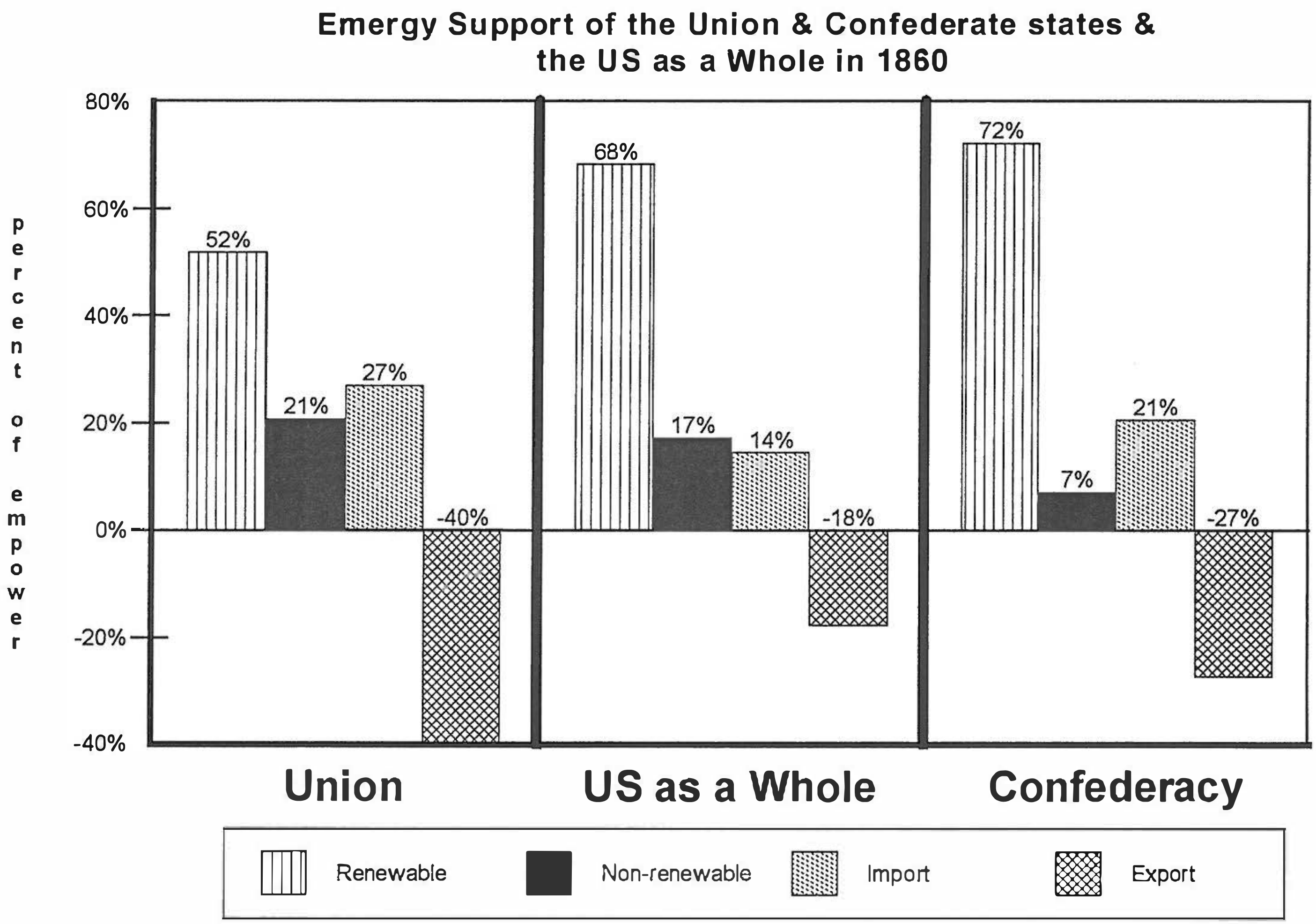
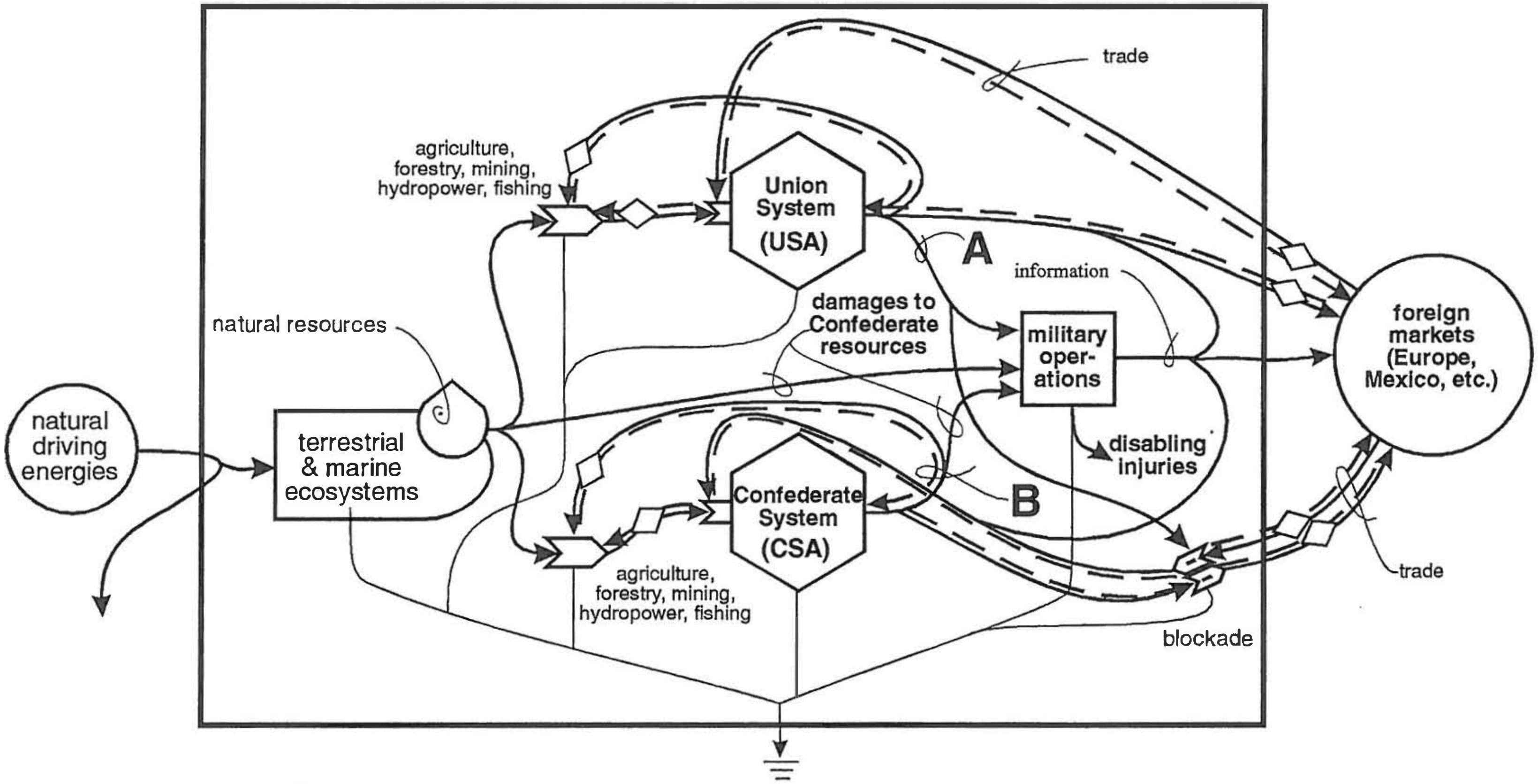


Figure 3-11. The renewable, non-renewable, import, and export emergy support of the Union states, the United States as a whole, and the Confederate states in 1860.

Table 3-27. Emergy of the requirements, flows, and destruction storages during the United States Civil War, 1861 - 1865.

Term	Item	Raw Units (J,$,g, etc.)	Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (1E20 sej)
Union Materiel				
1	Lead	4.10E+10 g	8.5E+09	3.47
2	Artillery projectiles	5.62E+10 g	1.1E+10	5.90
3	Gunpowder	3.97E+09 g	6.7E+09	0.27
4	Niter	4.10E+10 g	3.1E+09	1.27
5	Horses & mules, power	1.19E+06 head-y	7.2E+14	8.62
6	Horses & mules, deaths	1.71E+05 head	2.2E+15	3.71
7	Weapons	2.20E+10 g	1.1E+10	2.31
Union Troops				
8	Labor of troops	4.67E+06 person-y	6.6E+15	307.4
9	Deaths	3.34E+05 persons	1.1E+17	351.7
10	Disabling injuries	3.56E+04 persons	3.2E+16	11.2
11	P.O.W.s (lost labor)	1.46E+05 person-y	6.6E+15	9.6
Union Navy & Maritime Service				
12	Labor	3.98E+05 person-y	6.6E+15	26.2
13	Deaths	3.21E+01 persons	1.1E+17	0.034
14	Fuel	7.75E+17 J	3.3E+04	255.7
15	Weapons	6.47E+09 g	1.1E+10	0.68
16	Vessels	4.09E+11 g	(see calculations)	89.0
17	Lost Merchant Vessels	7.80E+10 g	(see calculations)	5.82
Union Government, Transport, & Other Support				
18	Union civil servants	3.50E+05 person-y	7.1E+15	24.9
Other				
19	Unaccounted for human services	(see calculations)		1496
Confederate Material				
20	Lead	4.54E+09 g	8.5E+09	0.38
21	Artillery projectiles	1.97E+10 g	1.1E+10	2.07
22	Gunpowder	7.00E+08 g	6.7E+09	0.047
23	Horses & mules, power	7.14E+05 head-y	7.2E+14	5.17
24	Horses & mules, deaths	1.71E+05 head	2.2E+15	3.71
25	Weapons	4.33E+09 g	1.1E+10	0.46
Confederate Troops				
26	Labor of troops	3.25E+06 person-y	1.2E+16	385.7
27	Deaths	2.45E+05 person	1.9E+17	465.8
28	Disabling injuries	3.04E+04 person	5.7E+16	17.3
29	P.O.W.s (lost labor)	1.61E+05 person-y	1.2E+16	19.1
Confederate Navy & Maritime Service				
30	Labor	1.20E+04 person-y	1.2E+16	1.4
31	Deaths	9.67E-01 persons	1.9E+17	0.0018
32	Fuel	3.31E+16 J	3.3E+04	10.9
33	Weapons	3.30E+09 g	1.1E+10	0.35
34	Vessels	6.99E+10 g	(see calculations)	89.0
35	Lost Blockade Running Vessels	1.94E+11 g	(see calculations)	78.5
Confederate Government, Transport, & Other Support				
36	Confederate Civil Servants	2.45E+05 person-y	1.2E+16	29.1
Other				
37	Unaccounted for human services	(see calculations)		958
Damages to Confederate Resources (decreased emergy storages)				
38	All property (unaccounted for services)	1.23E+09 $	1.0E+14	1275
39	Livestock	1.02E+16 J	1.0E+06	103
40	Farm equipment	4.62E+07 $	3.7E+13	17.3
41	Other property	1.20E+09 $	3.7E+13	447
42	Other storages	unknown		

Calculations in support of Table 3-27 are given in Appendix J.



A= Union Materiel, Troops, Navy, Government, & Other

B= Confederate Materiel, Troops, Navy, Government, & Other

Figure 3-12. A model of the U.S. Civil War showing categories of emergy given in Table 3-27.

(terms 8, 11, 12, 18 and 19)) were calculated to be the largest input to the Union war effort. The emergy embodied in soldiers who were killed or died (3.07E+22 sej (term 9)) was also a large input to the war effort as were the fuel used by the Navy and the emergy embodied in Naval vessels (3.45E+22 (terms 14 and 16)).

The evaluation of the Confederate war effort was similar to that of the Union with 1.39E+23 sej embodied in labor (terms 29, 29, 30, 36, 37), 4.65E+22 sej embodied in deaths of troops (term 27), 8.90E+21 sej embodied in Confederate naval vessels (term 34) and 7.85E+21 sej embodied in captured or destroyed blockade running vessels (term 35). The Confederacy also suffered equally large losses from damaged and destroyed buildings, machinery, fences, farm equipment, livestock, and rail roads (terms 38 through 42). The emergy conversion used for Confederate troops labor was the annual per capita empower for the Confederate states in 1860 (I19, Table 3-21). By the end of the War, the Confederate Army of Northern Virginia was largely supported by supplies run through the Union naval blockade (Wise, 1988). This support system was different than the system for which the 1860 per capita empower was calculated. However, because free environmental support or environmental services still contributed to the empower support, and because this environmental support was difficult to estimated for the Army alone, there was not enough evidence to suggest whether the per capita empower used is too high or too low. The Confederate per capita empower was higher than that used for the Union. This made the emergy values of Confederate troop labor and deaths slightly higher than those for the Union.

Summing the emergy of requirements, flows, and destruction of storages during the Civil War in order to estimate the total emergy impact of the War produced several values, depending on which estimates were used. The emergy of storages damaged was calculated from: 1.) the dollar value estimates for the damage multiplied by national emergy-money ratios (term 38, Table 3-27); and 2.) dollar value estimates of the actual material damaged multiplied by emergy conversions (terms 39, 40, and 41, Table 3-27). The first method estimated the total value of labor embodied in the damaged materials while the second method more conservatively estimated only the labor embodied in the original production of the material. It excludes labor used in transportation, maintenance, and other processes. If damage estimates calculated using one method were added to those calculated using the other method, some of the embodied labor would be double counted, thus the range of values. The range is 1.108E+23 sej to 2.604E+23 sej for the Union input to the War, 1.109E+23 sej to 2.067E+23 sej for the Confederate input to the War, 5.673E+22 sej to 1.275E+23 sej for the war damage to Confederate property, and 2.784E+23 sej to 5.946E+23 sej for the total impact of the War.

The evaluation of a hypothetical Civil War battle using data from the battle of Gettysburg is diagrammed in Figure 3-13 and the results given in Table 3-28. The total emergy of inputs to the battle and damage caused by the battle was 1.56E+21 sej. The dominant emergy characteristics of a battle were all human related. Troop deaths accounted for 90% of the emergy of a battle. The emergy values of next largest categories, disabling injuries to troops and the labor of troops, were each less than 4% of the emergy of troop deaths. All other categories were less than 1% of the emergy of troop deaths and 25% of the emergy of troop labor and disabling injuries. Environmental damage caused by the battle and the input of topography to the battle were not evaluated because of the lack of reliable data.

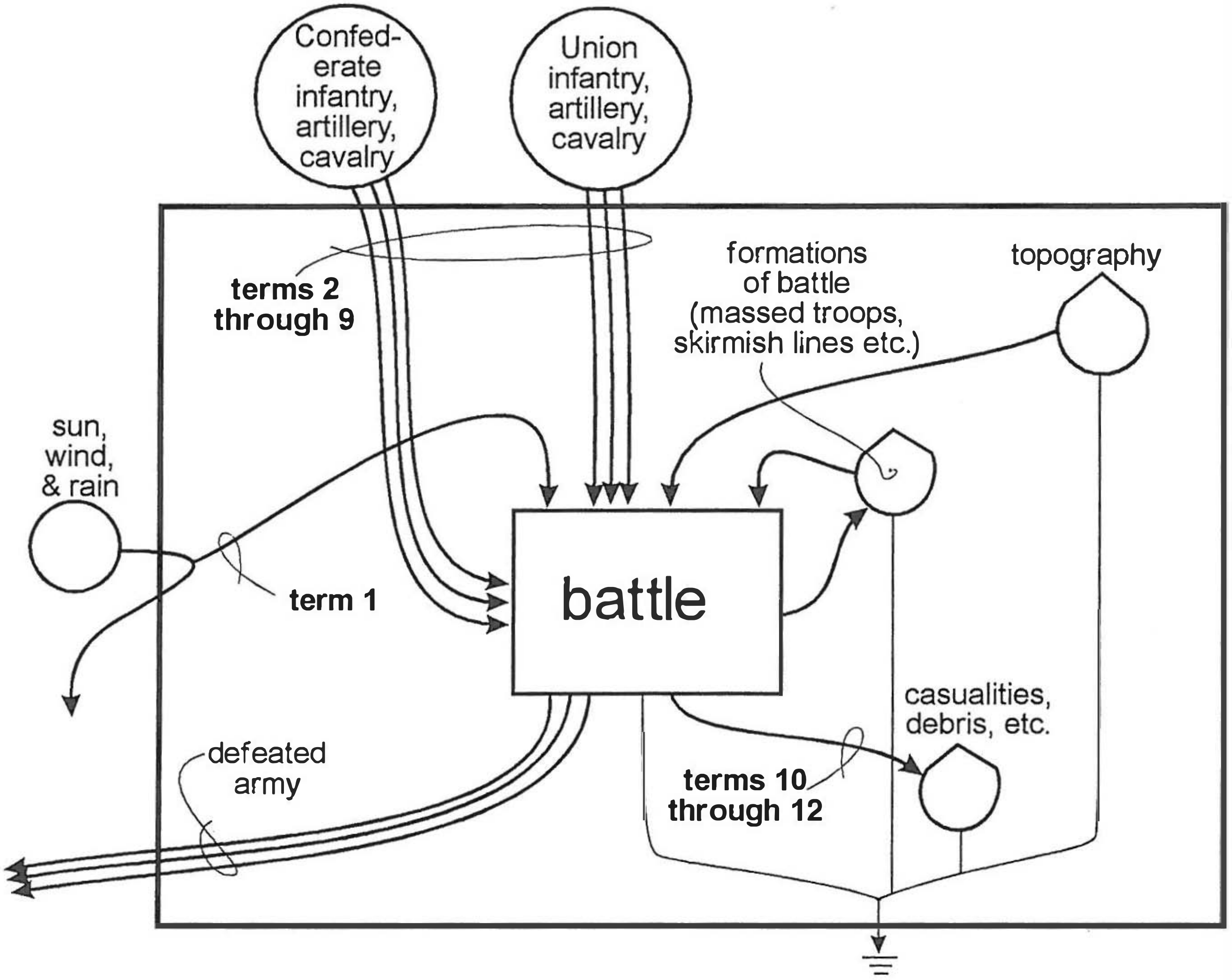


Figure 3-13. A model of a hypothetical U.S. Civil War battle. Terms are from Table 3-28.

Table 3-28. Emergy characteristics of a hypothetical civil war battle based on data from the battle of Gettysburg, 1-3 July 1863.

Term	Item	Raw Units	Solar Transformity or Emergy Conversion (sej/unit)	Solar Emergy (E18 sej)
1	Environmental support	(see calculations)		0.040
2	Lead	1.07E+09 g	8.5E+09	9.03
3	Artillery projectiles	1.28E+09 g	1.1E+10	13.46
4	Gunpowder	1.26E+08 g	6.7E+09	0.85
5	Horses & mules, power	6.71E+02 head-y	7.2E+14	0.49
6	Horses & mules, deaths	5.33E+03 head	2.2E+15	11.57
7	Small arms	6.82E+08 g	1.1E+10	7.17
8	Artillery cannon	4.22E+08 g	1.1E+10	4.43
9	Labor of troops	1.34E+03 person-y	7.1E+15	9.55
10	Wounded Troops	2.81E+04 persons	1.8E+15	49.86
11	Deaths	1.23E+04 persons	1.1E+17	1393.
12	Disabling injuries	1.68E+03 persons	3.4E+16	57.26
			Total of terms 1 through 12 =	1556.71

Calculations in support of Table 3-28.

All data are for the battle of Gettysburg, 1-3 July, 1863.

term:

1 Environmental support
area of battlefield = 1.0E+08 m^2 (estimated from Storrick (1932) and Luvaas and Nelson (1986))
duration of battle = 3 days (assumed)
terrestrial, environmental emergy inflow = 1.29E+08 sej/m^2-day (calculated for rain and earth cycle from US evaluations)
environmental emergy input to battle (sej) = (area) m^2 * (duration) days * (daily emergy inflow) sej/m^2-day
environmental emergy input to battle = 4.00E+16 sej

2 Lead
total lead use = 1.07E+09 g (estimated from "troops engaged" in term 9 assuming 60 rounds/day per troop engaged and 36.3 g lead/round)

3 Artillery projectiles =
Union artillery rounds = 3.28E+04 rounds (ORUCA, i-xxvii)
Confederate artillery rounds = 2.55E+04 rounds (estimated for Union use adjusted for the relative numbers of guns)
weight per round = 2.20E+04 g (assumed)
total artillery projectiles = 1.28E+09 g

4 Gunpowder
gun powder in cartridges = 1.14E+08 g (estimated "troops engaged" in term 9 assuming 60 rounds/day per troop engaged and 3.89 g powder/round)
gun powder in artillery rounds = 1.17E+07 g (estimated from term 3 assuming 200 g powder/round)
total gun powder issue = 1.26E+08 g

5 Horses and Mules, labor or power
number of animals = 8.16E+04 head (estimated from Nofi (1994) assuming Confederates had 60% of the number of Union horses)
battle duration = 3.00E+00 days (assumed)
total labor horses & mules = 6.71E+02 head-y ((head) * (battle duration) days * (1 y/365 days))

Table 3-28 continued.

term:			
6	Horses and Mules, animals killed or worn out		
	number of animals =	5.33E+03	head (estimated from Civil War evaluation as 15% of the value obtained by multiplying the ratio of Gettysburg human battle deaths to War human battle deaths by total War horse & mule deaths)
	This transformity assumes a 3 year maturation period for horses and is 3 times the transformity in term 5.		
7	Small Arms		
	Small arms =	1.63E+05	pieces (estimated as 1 piece/engaged troop)
	estimated wt. per piece =	4.18E+03	g (assumed)
	weight of small arms issue =	6.82E+08	g
	The transformity used was that calculated for finished iron.		
8	Artillery cannon		
	Union =	3.60E+02	pieces (Nofi, 1994)
	Confederate =	2.80E+02	pieces (Nofi, 1994)
	estimated wt. per piece =	6.59E+05	g (assumed)
	weight of cannon issue =	4.22E+08	g
	The transformity used was that calculated for finished iron.		
9	Labor of troops		
	Union troops engaged =	9.35E+04	persons (Livermore, 1900)
	Confederate troops engaged =	6.99E+04	persons (Livermore, 1900)
	battle duration =	3.00E+00	days (assumed)
	total labor of troops =	1.34E+03	person-y ((troops engaged) persons * (battle duration) days * (1 y/365 days))
	The transformity used is the annual per capita emergy use (I19) from the 1860 U.S. evaluation		
10	Wounded troops (excluding those who died of wounds (see term 11))		
	Union =	1.25E+04	persons (Livermore, 1900)
	Confederate =	1.56E+04	persons (Livermore, 1900)
	Total troops wounded (who did not die of wounds) =	2.81E+04	persons
	The transformity assumed an average 3 month recovery from wounds and was 25% of annual per capita empower (I19, U.S. 1860 evaluation).		
11	Deaths of troops =		
	Union troops, killed in action =	3.16E+03	persons (Livermore, 1900)
	Union troops, died of wounds =	2.08E+03	persons (estimated from Livermore's (1900) data for wounded, McPherson's (1992) estimate for wounded who died, and the "died of wounds"/"killed in action" ratio from Phister's (1883) data)
	Confederate troops, killed in action =	3.90E+03	persons (Livermore, 1900)
	Confederate troops, died of wounds =	3.12E+03	persons (estimated from Livermore's (1900) data for wounded, McPherson's (1992) estimate for wounded who died, and the "died of wounds"/"killed in action" ratio from Phister's (1883) data)
	Total deaths attributable to the battle =	1.23E+04	persons
	The transformity used is 16 times the annual emergy use per person from the U.S. 1860 evaluation. This transformity assumes 16 years are required for human maturation.		
12	Disabling injuries to troops		
	total number discharges due to wounds =	1.68E+03	persons (calculated from "died of wounds" using the French World War I statistic suggested by Beringer et al. (1986) of the number discharged for wounds as 32.3% of number killed) This transformity is assumed to be 30% of the transformity used for war deaths.

CHAPTER 4
DISCUSSION

Comparison of Nineteenth- and Twentieth-Century Emergy Inputs

This study's discussion can be divided into two broad categories, comparisons of this study's results with those of previous studies and a discussion of this study relative to the broader fields of ecology, general systems, and the social sciences. The basis for the first category of discussion, a summary of the nineteenth-century transformities, emmassities, emergy-dollar ratios, and other emergy conversions calculated in this study (Tables 3-1 tbrough 3-25), is given in Table 4-1. These conversions compared favorably with those given in Table 2-1 and those given by Odum and Odum (1983) and Odum (1994). A comparison of the nineteenth- and twentieth-century values is also ideal for analyzing the potential for emergy to contribute to the fields of history and social science.

Corn, Pork, and Cotton

The 8.4E+04 sej/J transformity calculated for corn produced on slave labor plantations (Table 3-1) was larger than the 2.7E+04 sej/J transformity given for primitive corn by Odum and Odum (1983), but only slightly more than the 7.7E+04 sej/J transformity calculated by Odum (1994) for corn produced using intensive agriculture. The transformity calculated for corn also exceeded those calculated for low and high intensity rice production (4.8E+04 and 5.5E+04 sej/J) by Brown and McClanahan (1992). The high transformity for corn in 1860 might be in part accounted for by the relatively low yield per acre (or square meter) and high unit labor input. The

Table 4-1. A summary of the nineteenth-century transformities, emmassities, emergy-money ratios and other emergy conversions calculated in this study.

form	conversion		source
Corn	8.4E+04	sej/J	Table 3-1
Water-power	1.4E+05	sej/J	Table 3-2
Cotton, ginned	4.4E+05	sej/J	Table 3-1
Pork	1.0E+06	sej/J	Table 3-1
Steam engine-power	1.5E+06	sej/J	Table 3-2
Gunpowder	2.0E+06	sej/J	Table 3-3
Iron, finished product	6.5E+08	sej/J	Table 3-5
Sulfur	1.9E+09	sej/g	Table 3-3
Niter	3.1E+09	sej/g	Table 3-3
Iron, pig	4.6E+09	sej/g	Table 3-5
Gunpowder	6.7E+09	sej/g	Table 3-3
Lead pig	7.9E+09	sej/g	Table 3-4
Lead, finished product	9.0E+09	sej/g	Table 3-4
Iron, finished product	1.1E+10	sej/g	Table 3-5
U.S. emergy-money ratio, 1870	3.0E+13	sej/$	Table 3-14
Great Britain emergy-money ratio	6.7E+13	sej/$	Table 3-17
U.S. emergy-money ratio, 1860	7.4E+13	sej/$	Table 3-11
Union states emergy-money ratio, 1860	7.5E+13	sej/$	Table 3-25
U.S. emergy-money ratio, 1850	8.3E+13	sej/$	Table 3-8
Confederate states emergy-money ratio, 1860	1.0E+14	sej/$	Table 3-21
Great Britain emergy-money ratio	3.3E+14	sej/£	Table 3-17
Slave labor, U.S.	3.3E+13	sej/labor-day	Table 3-18
Slave labor, U.S.	9.0E+15	sej/labor-year	Table 3-18
U.S. 1870 empower per person	6.5E+15	sej/person-year	Table 3-14
U.S. 1850 empower per person	6.8E+15	sej/person-year	Table 3-8
U.S. 1860 empower per person	7.1E+15	sej/person-year	Table 3-11
Union states 1860 empower per person	7.5E+15	sej/person-year	Table 3-25
Great Britain 1860 empower per person	7.6E+15	sej/person-year	Table 3-17
Confederate states 1860 empower per person	1.2E+16	sej/person-year	Table 3-21

Table 4-1. A summary of the nineteenth-century transformities, emmassities, emergy-money ratios and other emergy conversions calculated in this study.

form	conversion		source
Corn	8.4E+04	sej/J	Table 3-1
Water-power	1.4E+05	sej/J	Table 3-2
Cotton, ginned	4.4E+05	sej/J	Table 3-1
Pork	1.0E+06	sej/J	Table 3-1
Steam engine-power	1.5E+06	sej/J	Table 3-2
Gunpowder	2.0E+06	sej/J	Table 3-3
Iron, finished product	6.5E+08	sej/J	Table 3-5
Sulfur	1.9E+09	sej/g	Table 3-3
Niter	3.1E+09	sej/g	Table 3-3
Iron, pig	4.6E+09	sej/g	Table 3-5
Gunpowder	6.7E+09	sej/g	Table 3-3
Lead pig	7.9E+09	sej/g	Table 3-4
Lead, finished product	9.0E+09	sej/g	Table 3-4
Iron, finished product	1.1E+10	sej/g	Table 3-5
U.S. emergy-money ratio, 1870	3.0E+13	sej/$	Table 3-14
Great Britain emergy-money ratio	6.7E+13	sej/$	Table 3-17
U.S. emergy-money ratio, 1860	7.4E+13	sej/$	Table 3-11
Union states emergy-money ratio, 1860	7.5E+13	sej/$	Table 3-25
U.S. emergy-money ratio, 1850	8.3E+13	sej/$	Table 3-8
Confederate states emergy-money ratio, 1860	1.0E+14	sej/$	Table 3-21
Great Britain emergy-money ratio	3.3E+14	sej/£	Table 3-17
Slave labor, U.S.	3.3E+13	sej/labor-day	Table 3-18
Slave labor, U.S.	9.0E+15	sej/labor-year	Table 3-18
U.S. 1870 empower per person	6.5E+15	sej/person-year	Table 3-14
U.S. 1850 empower per person	6.8E+15	sej/person-year	Table 3-8
U.S. 1860 empower per person	7.1E+15	sej/person-year	Table 3-11
Union states 1860 empower per person	7.5E+15	sej/person-year	Table 3-25
Great Britain 1860 empower per person	7.6E+15	sej/person-year	Table 3-17
Confederate states 1860 empower per person	1.2E+16	sej/person-year	Table 3-21

U.S. yield per acre in 1860 was less than half the yield in 1970, while the labor input per acre of harvested corn was over four times greater than that in 1970 (USDC, 1975).

While transformities for domestic ruminants have been calculated (Odum and Odum, 1983), there are as of yet no other transformities with which to compare this study's 1.0E+06 sej/J transformity for pork (Table 3-1). This study's value was similar to the 1.7E+04 sej/J transformities for mutton and beef given by Odum and Odum (1983) and Odum et al. (1987a), but less than their 4.0E+04 sej/J transformity for veal. This study's transformity for pork was similar to Woithe's (1992) 1.1E+06 sej/J value for un-harvested shrimp, squid, herring, and greenling. The 4.4E+05 sej/J transformity for ginned cotton in 1860, calculated in Table 3-1 was roughly half of the Odum et al. (1987a) 8.6E+05 sej/J value for upland Texas cotton in 1981. Pesticides and labor were the largest inputs to the 1981 transformity, accounting for over two-thirds of the emergy.

This studies transformity calculations for corn, cotton, pork, and slave labor (Tables 3-1 and 3-18) were dependent upon one another. The transformities were not particularly changed by varying their respective inputs across reasonable ranges. The corn and cotton transformities might have been improved by using the water evapotranspired by the crops as their environmental emergy input. This technique would have required better data for crop-specific erosion in the nineteenth century, data which were not available. The technique used in Table 3-1 estimated a fraction of the emergy incident upon the crop fields as the natural emergy input instead of using evapotranspiration data in order to try to account for the emergy loss of erosion. In the absence of erosion data, this technique appeared to be the better of the two.

Water-Power and Steam Engine-Power

Water-power and steam engine-power drove the manufacturing industries of the mid-nineteenth century. Because of this, changes over time of these power sources' transformities can provide important insight into the U.S. during the nineteenth century. The 1.4E+05 sej/J transformity calculated for water-power and the 1.5E+06 sej/J value calculated for steam engine-power (Table 3-2) exceed those given by Odum (1994) for coal (before use (3.3E+04 sej/J)) and for crude petroleum (5.3E+04 sej/J) (Table 2-2). The water-power transformity was essentially the same as the transformity for pre-industrial revolution charcoal calculated by Sundberg et al. (1994a). The similarity between transformities for these two sources of energy might explain the large, widespread, and persistent use of wood and wood charcoal in the nineteenth-century U.S. In terms of energies of all qualities (not emergy), wood and wood charcoal constituted 90% of the nation's total energy use in 1850 and continued to supply a large portion of the total energy well into the late 1800s. The use of wood increased with the increasing energy demands of the evolving industrial revolution until finally being surpassed by coal in the 1880s (Pratt, 1980); again in terms of energy not emergy. Measured in emergy, the use of coal overtook the use of wood between 1860 and 1870 (Tables 3-9 and 3-12).

Pratt (1980) explained important factors in the pattern of United States industrial development. He first cited the availability of water-power as the driving force that caused the eastern U.S. to industrialize before other regions. He then described the decline of the Northeast and the rise of the Midwest as being driven by the growing use of coal, which was inexpensive and abundant in the Midwest but expensive to transport to the North East. According to this set of explanations, the West and Southwest regions were energy poor and suffered from the high cost of transporting coal to the regions until the discovery of oil and natural gas around 1900. According to the explanation, this discovery of oil provided the cheap energy base to fuel the regions' development.

These explanations were based on monetary costs, but there is an alternative set of explanations using net emergy yield ratios. Charcoal was used throughout the U.S. in the 1800s, but appears not to have had as great an ability to drive industrial development as water-power. This can be explained by the different emergy yield ratios of the two energy sources. While they have the same transformities, the free environmental or harvested inputs were 1.1E+05 sej/J power output for falling water (Table 3-2), verses 2.1E+04 sej/J heat output for charcoal (from the Doherty et al. (1993) standing timber transformity). These inputs had respective net emergy yields of 3.5 for water-power and 1.2 for charcoal. The water-power yield was higher because water-power production made use of topography that created water falls or steeply inclined rivers. This topography was the result of the previous work of water and geologic cycles. The previous work was, in effect, stored emergy and accessing this emergy resulted in the higher net emergy yield.

The larger net emergy yield ratio of water-power made it a primary energy source with significantly more potential than charcoal. The increased net emergy yield of water-power translated directly into the ability sustaining more and more intensive manufacturing than charcoal. Coal, and in turn oil, supplanted water-power because they had better (higher) net emergy yield ratios and possibly more potential to do work. Pratt (1980) was correct in asserting that the higher cost of coal in the Northeast affected the region's development, but monetary cost was only of secondary importance. The most important coal transport costs were the iron and wood used in the transporting railroads and barges and the coal used directly in transport and indirectly in manufacturing the transportation equipment.

Separating the concept of cost from energy and material constraints (thereby making cost a strictly monetary measure) is not an uncommon problem in the social sciences. In a debate in the *Journal of Environmental Economics and Management* about the relationship of entropy and natural resource scarcity (Young, 1991; 1994; Daly, 1992; Townsend, 1992), Young failed to recall that all matter contains energy when he argued that there was no analog for matter (and for materials) to the relationship between energy and available energy. The analog for matter is available energy itself. The failure to realize that matter contains energy may be analogous to the failure to realize that humans are not separate from nature; a problem that has often plagued environmentalism (see Grizzle (1994) and Salzman (1994) among others).

It would be of some academic value to know if these two problems had a common ancestor and were homologous as well as analogous. In interdisciplinary studies, the combination of distantly homologous concepts into a single model (conceptual or numerical) has a greater potential to double or even square the effect of the common concept than for research in a single field. When homologous concepts are combined from two dissimilar fields, there is more likelihood that the researcher will be unaware of their common origin. And, because the concepts are brought in from outside the model, typical sensitivity analyses will not express the influence of common concept on the model.

The transformity calculations for water- and steam-power might be improved with more precise machinery depreciation and labor data. However, these inputs contributed small amounts of emergy to the final transformity values. As a result, varying the values for labor and machinery inputs across the reasonable range of potential values did not significantly change the transformities (e.g. the calculations are not sensitive to these values). Thus, more precise labor and machinery data are not likely to improve the accuracy of the transformities.

Gunpowder, Sulfur, and Niter, and Lead and Lead Pig

In contrast with the evaluation of agriculture where modern transformities were lower than those of the nineteenth century, the 9.0E+09 sej/g emmassity for lead produced in 1860 is almost an order of magnitude lower than the 7.3E+10 sej/g emmassity calculated by Pritchard (1992) for lead produced in the 1980s. A large portion of this difference is due to the two different values used for the lead content of ores. The much higher lead content estimate used for 1860 ore might only be valid for certain ore deposits and not representative of the worldwide extraction of ore in 1860. However, the substitution of the Pritchard's higher transformity for the value calculated in Table 3-4 did not significantly affect the outcome of any of the analyses in this study. Several of the other nineteenth-century material emmassities were similar to modern emmassities. The 1.9E+09 sej/g sulfur and 3.1E+09 sej/g niter emmassities calculated for nineteenth-century products were similar to those calculated by Pritchard for modern diatomite (2.0E+09 sej/g) and hydrated lime (1.6E+09 sej/g). Pritchard's emmassity value for mined but not processed modern sulfur was 1.1E+09 sej/g, even closer to the 1.9E+09 sej/g nineteenth-century value for sulfur. In addition, Pritchard's 7.5E+09 sej/g emmassity for caustic soda (NaOH) was similar to the 6.7E+09 sej/g emmassity calculated for nineteenth-century gunpowder.

Iron and Pig Iron

The 1.1E+10 sej/g transformity calculated for finished iron produced using coal as a fuel was essentially the same as the 1.3E+10 sej/g calculated by Sundberg et al. (1994a; 1994b) for seventeenth-century Swedish bar iron produced using charcoal. This study's 1.1E+10 sej/g calculation excluded the inputs to equipment used in mining, reduction, refining, and ore transportation, fuels used in mining and transportation, and labor inputs to transportation. The value of the fuel and equipment input to mining were probably insignificant compared to that of reduction and refining. The 1860 census gives the capital of iron ore mining firms as $2,200,000, and their materials cost as $440,000. In contrast, pig and finished iron producing firms had combined capital of $48,000,000, and combined materials costs of $34,000,000.

The inputs to transportation appear to have been similarly small. A study in *Mechanics Magazine* (Anonymous, 1836) reported the coal requirements to transport 1 gram of train and cargo 1 kilometer as 2.4E-04 Joule, which, assuming a coal transformity of 4.4E+04 sej/J, was equivalent to 10 sej per g-km of transport. The average lifespan (calculated in terms of dollar costs) of 1860s railroad rolling stock was estimated to be 650,000 km (Williams, 1870); which was the point at which repair and maintenance dollar-costs equaled the purchase dollar-cost. This input to the transformity of transportation was small for two reasons. First, the lifespan of the majority of rolling stock material was well over 1 million km (Williams, 1870). Second, the replaced material still had a fairly high transformity as scrap metal, at least equal to that of pig iron (4.6E+09 sej/g if the transformity is taken to be the same as that of pig iron calculated in this study (Table 3-5)).

This study's transformity calculation for iron production uses fuel, material, and labor data from England combined with labor and material data the from United States. It is conceivable that the U.S. foundries made greater use of water-power than their English counterparts. The coal fueled production was considered more advanced than water-powered production (Wertime, 1962), and without actual data it was difficult to estimate how increased use of water-power affected the transformity of the iron product. Charcoal fueled processes accounted for forty percent of the

1860 production of pig iron in Pennsylvania, a primary center of U.S. production (Walsh, 1967). Sundberg et al. (1994a), using data from early Pennsylvania as well as Swedish iron production, found the emergy value of wood and charcoal in early pig iron production to be approximately 18% of the total empower of production. Bache (1837) reported increases in charcoal fuel use efficiency of less than 33% with the use of improved furnaces. Using these 1837 data for improved furnaces changed the Sundberg et al. transformity by less than 6%. As such, the Sundberg et al. transformity appeared to be an acceptable value for the transformity for 1860 charcoal produced pig iron.

The apparent decrease in the transformity of pig iron from 1.3E+10 to 4.6E+09 sej/g with improvements in production technology may be an important observation in itself. If the difference between the two transformities was significant (e.g. not the product of different evaluation techniques), the change may be evidence of a system of production evolving towards more efficient emergy use by decreasing a net emergy yield ratio. Additionally, the difference could be evidence in support of the maximum-empower principle if the evolution was driven by forces that selected for the most effective use of emergy.

Nineteenth-Century and Modern Prices and Emergy Values

A direct comparison of prices in the nineteenth century to modern prices can be misleading because industrialization and other factors have decreased prices relative to income (Nofi, 1992). A comparison of incomes and emergy support in 1870 and 1980 (Table 4-2) expresses some of the information that might be derived from a comparison of prices. United States per capita empower support increased 446% from 1870 to 1980 while per capita income increased 5,580%. At the same time, the U.S. population increased 614% while the U.S. gross national product increased 31,640%. This suggests a large decline in the natural resource and environmental services buying power of the U.S. dollar from 1870 to 1980 when compared in current dollars of the two years.

Table 4-2. A comparison of some emergy and economic indices in 1870 and 1980.

Index	**Value**		**Percent of 1870 Value**	**Percent of 1980 Value**
1870 Per Capita Empower[a]	**6.5E+15**	sej/person-y		**22.4%**
1980 Per Capita Empower[b]	**29.0E+15**	sej/person-y	**446%**	
1870 Population[c]	**3.7E+07**	people		**16.3%**
1980 Population[d]	**22.7E+07**	people	**614%**	
1870 Emergy-Money Ratio[a]	**30.0E+12**	sej/$ (1870 dollars)		**1,150%**
1980 Emergy-Money Ratio[b]	**2.6E+12**	sej/$ (1980 dollars)	**8.7%**	
1870 Per Capita Income[e]	**170**	$/person-y (1870 dollars)		**1.8%**
1980 Per Capita Income[d]	**9,489**	$/person-y (1980 dollars)	**5,580%**	
1870 Gross National Product[f]	**8.3E+09**	$ (1870 dollars)		**0.32%**
1980 Gross National Product[d]	**2626.1E+09**	$ (1980 dollars)	**31,640%**	

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[a] Table 3-14.
[b] Odum et al. (1987a).
[c] USCO (1874).
[d] USDC (1981).
[e] From USDC (1975).
[f] From Gallman (1966).

The United States in 1850, 1860, and 1870, and Great Britain in 1860

The development of an accurate and justifiable method for determining the renewable empower support of rural systems (where political boundaries did not necessarily define the true boundaries of systems) is an important early step in many historical emergy evaluations. Sundberg et al. (1994a, 1994b) recognized this question in their evaluation of seventeenth-century Sweden. Four different methods of calculating empower support for the U.S. in 1860 are compared in Table 4-3. Method 2, the "Farmed Area" method was used in this study's national emergy evaluations. As the table suggests, the choice of methods can make a large difference in the results, up to an order of magnitude in some cases. The questions inherent in the evaluation will in part determine which method is appropriate. Policy evaluations concern potential use as well as actual use of emergy, thus the prevalence of the political area method (method 4) in many national emergy evaluations (Odum and Odum, 1983; Doherty and Brown, 1992; Woithe, 1992). Historical evaluations will frequently be more concerned with actual emergy use and will therefore be restricted to the more conservative evaluation methods (methods 1 through 3). The results of the evaluations in this study were dependent upon the choice of the farmland method. The separate evaluations had similar sensitivities to the value of the renewable empower support term however, and changes in the value of this term (from using different calculation methodologies) affected individual evaluation values but not their values relative to one another and therefore study's overall results . The use of farmland areas may have overestimated the empower of the nineteenth century, but the large use of wood (for fuel and material) harvested off farmland limited the overestimation.

The fact that emergy values calculated in different years can be compared (unlike many other indices (e.g., prices and G.N.P.) allows for several interesting comparisons of different systems in different years. Comparisons of the emergy support of the United states in 1850, 1860, 1870, and 1983 and of the U.S. as a whole, the Confederate and Union states, and Great Britain are given in Figures 4-1 and 4-2 respectively. Figure 4-1 shows a U.S. system in 1983 that was

Table 4-3. Total human system use (I5), annual per capita empower (I19), and emergy- money ratios (I20) calculated for the United States in 1860 using four methods.

Method	Total Human System Use (U) (1E20 sej/y)	Annual Per Capita Empower (1E15 sej/person-y)	Emergy-Money Ratio (1E12 sej/$)
1 Direct Use	1800	5.6	58
2 Farmed Area	2200	7.1	74
3 2 Person / mi^2	5000	16.	170
4 Total Political Area	7000	22.	240

Method:

1 Direct Use: calculated as the sum of the emergies of the agricultural, forestry, fishery, hydropower, and non-renewable resources and the imports used by the system in the evaluation year (sum of terms 8 through 47 excluding term 37 (Table 3-9)).

2 Farmed Area: calculated as described in the Methods section as the natural emergy incident upon the farmed area of the U.S. (Figure 1-2) and a fraction of the continental shelf added to non-renewable resources extracted and the imports in the evaluation year. Results are given in Tables 3-9, 3-10, 3-11.

3 2 Person Per Square Mile: calculated as in term 2 above and Table 3-9 except the natural emergy incident upon areas with a population density of 2 people/mi^2 (2.18E+12 m^2)or greater and a larger fraction of the continental shelf (50% or 3.33E+11 m^2) were used.

4 Total Political Area: calculated as in terms 2 and 3 above and Table 3-9 except the natural emergy incident upon the entire political area of the U.S. (3.15E+12 m^2) in 1860 and the entire continental shelf (6.67E+11 m^2) were used.

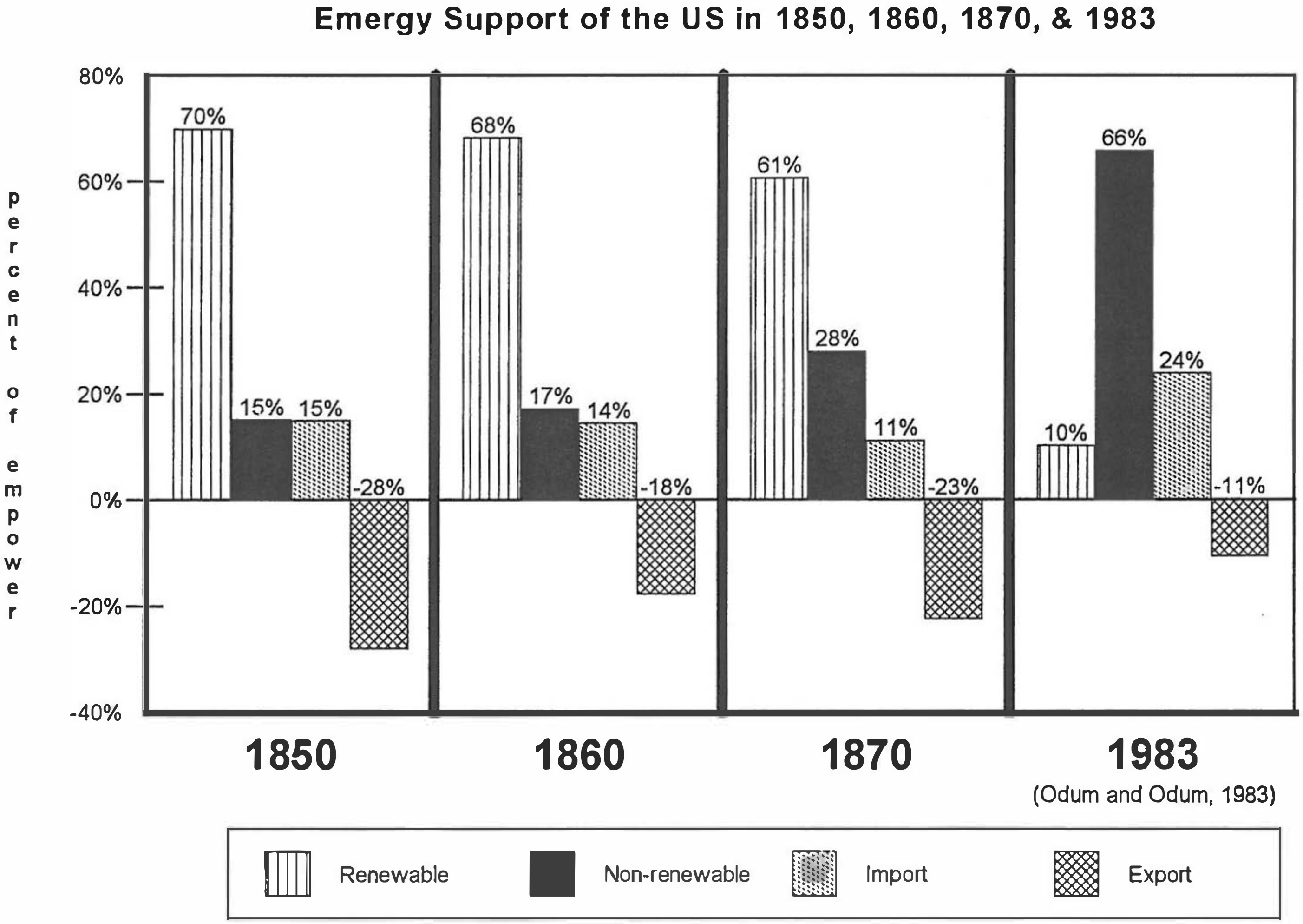

Figure 4-1. A comparison of the renewable, non-renewable, import, and export emergy support of the United States in 1850, 1860, 1870, and 1983.

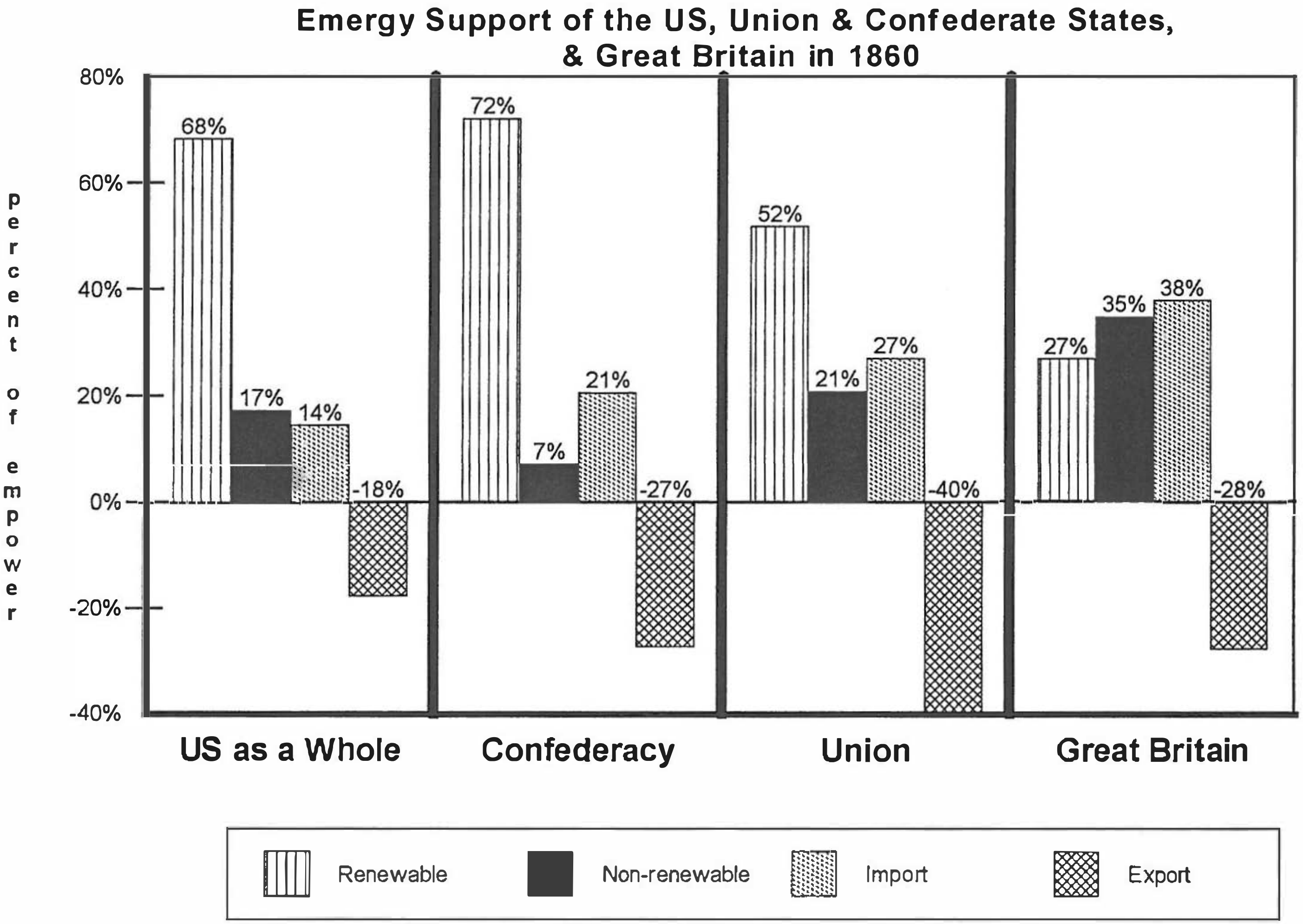

Figure 4-2. A comparison of the renewable, non-renewable, import, and export emergy support of the United States as a whole, the Confederate and Union states, and Great Britain in 1860.

drastically different than the nineteenth-century U.S. systems. This difference can be seen in the dramatic increase in the use of non-renewable emergy in 1983, coupled with a similarly intense decrease in the relative percentage of the emergy derived from renewable sources. The difference was probably indicative of changes brought on by the later stages of the industrial revolution. Though the U.S. had passed through the first stage of the industrial revolution by 1860, Great Britain had progressed significantly farther (Woodman, 1980). Figure 4-2 shows 1860 Great Britain with a high use of non-renewable emergy intermediate between the U.S. in 1860 and the U.S. in 1983.

Other important differences identified between the nineteenth- and twentieth-century U.S. systems were the relative percentages of imports and exports (evaluated in emergy units) and the net benefit in trade the U.S. enjoyed in 1980. In 1980 imports exceeded exports by roughly 2 to 1. In 1850, 1860, and 1870, though the ratios varied, exports always exceeded imports. The fact that Great Britain's 1860 imports exceeded exports (Figure 4-2) supports a conclusion that the difference between the U.S. systems was the result of the much increased industrialization of the twentieth-century U.S. in relation to its nineteenth-century predecessor. Great Britain was at the height of its colonial empire in the second half of the nineteenth century. As such, the similarity between the 1980 U.S. and 1860 Great Britain trade characteristics might also suggest a change in the relationship between the U.S. and its trading partners towards those of a colonial system. It is unlikely that this change in trading partner relationships occurred independent of changes in U.S. industrialization, however.

The changes in the United States empower bases from 1850 to 1870 given in Figures 4-3 and 4-4 suggest a gradual, steady evolution of the U.S. system from 1850 to 1870. This pattern of evolution supports certain aspects of the Cochran thesis (Cochran, 1961), which holds that the Civil War retarded the U.S. industrial revolution. The renewable emergy support of the U.S. increased from 1850 to 1860, but did not change between 1860 and 1870 (Figure 4-3). This particularly supports Cochran if one accepts the ideas of economic historians such as Woodman (1980), who see the industrialization of U.S. agriculture as one of the driving factors behind the

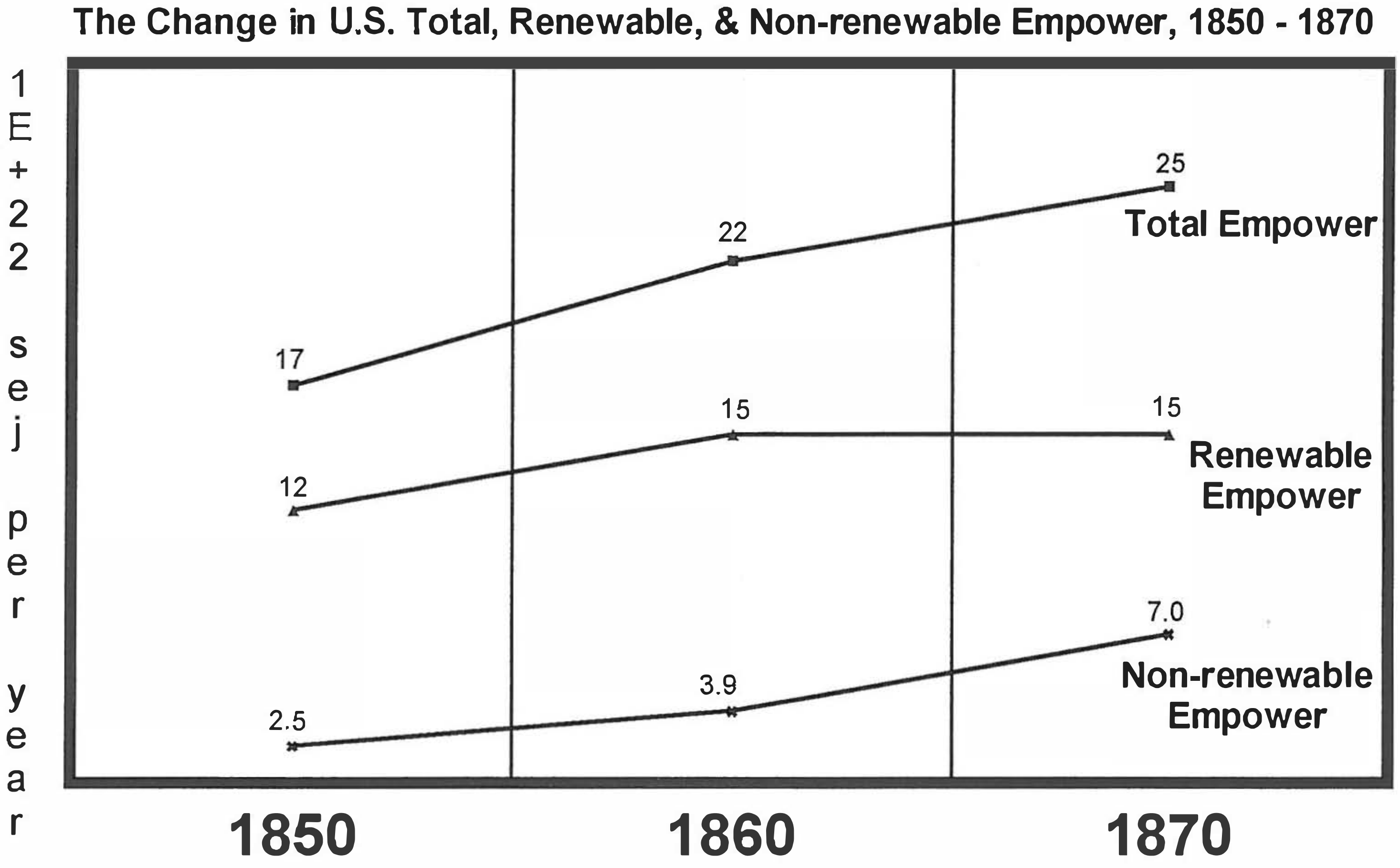

Figure 4-3. The change in the United States total, renewable, and non-renewable empower from 1850 to 1870.

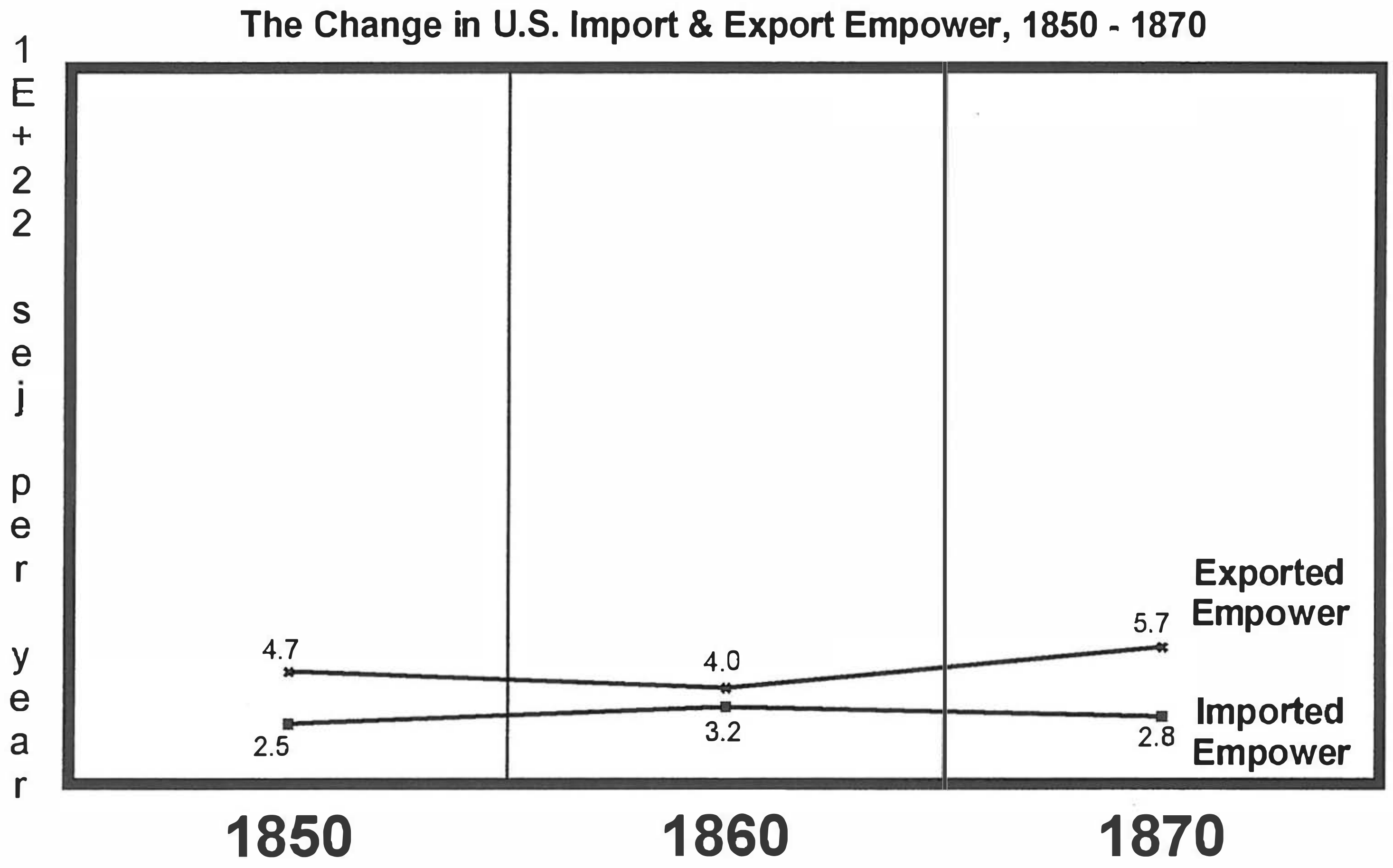

Figure 4-4. The change in the United States imported and exported empower from 1850 to 1870.

U.S. industrial revolution. The fact that empower support did not change, was a result of the calculation method coupled with the War's damage to Southern farms which decreased the area farmed in the South at the same time the area of farms in the midwest was increasing. The halving of the U.S. emergy-money ratio between 1860 and 1870 was likely the result of large war-induced inflation in a system that was growing steadily (in terms of manufacturing output and agricultural production) but not at the same pace as monetary inflation.

Cochran's thesis contrasted with a much earlier idea put forth by historians such as Beard (1927) (and later argued by historians like Hacker (1940) and Salsbury (1967)) which held that the Civil War initiated the industrial revolution. The smooth steady change in empower values observed in this study seem to correspond best with Engerman's (1966) hypothesis that, in the long run, the Civil War neither greatly retarded nor advanced the industrial revolution. These evaluations only analyzed mining, logging, and other primary resource uses, though. A post-war recession could have retarded primary resource uses while secondary resources uses like the construction of factories was occurring or while factories and other capital built or accumulated during the War was idle. This capital could then have contributed to industrial expansion in the 1880s and 1890s. These issues have already been the subject of considerable debate among economists. Regardless, that the results of this study should support a commonly accepted hypothesis of economic history is in itself significant because the results were not calculated using economic techniques, only emergy techniques.

The nineteenth-century evaluations of the U.S., Confederate states, Union States, and Great Britain are compared to those of 18 other countries in Table 4-4. Several of these evaluations used a method akin to the total political area method in Table 4-3 because they were designed as policy rather than historical studies and were focused on potential uses. In terms of empower density (sej/m^2), the nineteenth-century United States appeared most similar to India, Brazil, Thailand, and Papua New Guinea in the 1980s. In terms of emergy support from imports (emergy use from within) the U.S. in 1850, 1860, and 1870 was most similar to Brazil, Australia, Liberia, the U.S. (in 1983), and Ecuador. Per capita emergy use placed the nineteenth-century

Table 4-4. A comparison of emergy indices for the nineteenth-century U.S. and Great Britain to those for 17 other nations in the 1980s and for seventeenth-century Sweden.

System[a]	Empower Density E11 sej/m^2-y	Emergy Use From Within %	Per Capita Emergy Use E15 sej/person-y	Emergy-Money Ratio E12 sej/$
Netherlands	100.	23	26	2.2
Puerto Rico (1992)	74.	2.0	18.	1.6
Sweden	57.	30	28	1.5
Taiwan	37.	24	8.0	2.5
Switzerland	18.	19	12	0.70
Poland	11.	66	10	6.0
Dominica	8.8	69	13	15.
U.S.A.	7.0	77	29	2.3
Great Britain, 1860	**5.2**	**61**	**7.6**	**67**
Liberia	4.2	92	26	35.
Ecuador	3.4	94	10	8.5
Spain	3.1	24	6.0	1.6
New Zealand	2.9	60	26	3.0
Papua New Guinea	2.6	96	35	48.
Thailand	2.2	70	3.0	3.7
Brazil	2.1	91	15	8.4
India	2.1	88	1.0	6.4
U.S.A., 1870	**1.5**	**88**	**6.5**	**30.**
Union states	**1.4**	**72**	**7.5**	**75.**
Confederate states	**1.4**	**79**	**12**	**100.**
U.S.A., 1860	**1.4**	**85**	**7.1**	**74.**
U.S.A., 1850	**1.4**	**85**	**6.8**	**83.**
Australia	1.4	92	59	6.4
Sweden, 1600s	0.41	n.a.	4.0	n.a.

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[a] The nineteenth-century values were calculated in this study (Tables 3-9 through 3-25). The values not calculated in this study are from Odum and Odum (1983) except for the following: Puerto Rico (Doherty et al., 1994), Sweden (Doherty et al., 1993), Taiwan (Huang and Odum, 1991), Ecuador (Odum and Arding, 1991), Papua New Guinea (Doherty and Brown, 1992), Thailand (Brown and McClanahan, 1992), and Sweden in the 1600s (Sundberg et al., 1994a).

U.S. in line with Taiwan, Spain, Poland and seventeenth-century Sweden. In general, comparisons of emergy-money ratios are more suspect than those of other emergy statistics because of the exchange ratios involved. Nevertheless, the nineteenth-century U.S. money ratio is strikingly different from the majority of the other evaluations. It is most similar to Papua New Guinea and Liberia.

The statistics for the more developed countries in Table 4-4 offered the most accurate comparison with the nineteenth-century evaluation (assuming that the most developed countries used most of their renewable emergy). Many of the countries most similar to the nineteenth-century U.S. were also the least developed, which weakened confidence in the comparisons. Support for the comparisons can be found in the fact that (with the exception of empower density) the emergy statistics of Union states and Great Britain in 1860 were fairly similar. The fact that Union states were similar to Great Britain lends support to the emergy evaluation methods because the Union states were significantly more industrialized than the Confederate states.

Emergy Basis of The Union and Confederate States and the Civil War

Comparisons of the Union and Confederate states have been the basis of, or at least used to introduce many Civil War studies (see for example Donald (1960), Beringer et al. (1986), and McPherson (1992)). Because of this, this study's evaluation of the emergy support characteristics of the Union and Confederate systems and the methods by which the systems used their support offers a good opportunity to discuss well known aspects of history in emergy terms. Annual empower support, the broadest emergy index, showed the Union and Confederate systems to be more similar than many recent quantitative presentations of the two (McPherson (1992) for example) would suggest. The similarity in annual empower indices (1.0E+23 sej/y and 1.5E+23 sej/y for the Confederacy and Union respectively) was largely the result of the two systems having similar amounts of land in agricultural production. The per capita empower support for the

Confederacy was higher than that for the Union because the Confederacy had more farmland in production per capita.

The sum of the annual empowers of the Confederate (1.0E+23 sej/y) and Union (1.5E+23 sej/y) states in 1860 was slightly higher than the U.S. as a whole in 1860 (2.3E+23 sej/y). The amounts of imports and exports for the two systems relative to their total emergy use were also much higher than for the U.S. as a whole. These import-export differences were the result of double-counting that occurred when the sum of the Union and Confederate empowers was compared to the U.S. empower. Human services embodied in imports and exports between the Confederacy and the Union increased the total emergy use of the two systems (relative to the U.S.) because human services embodied in exports were not subtracted from the exporting system's total emergy use. When the Confederate and the Union empowers were combined, the emergy values of these services were counted twice, first, as the original emergy flowing into the exporting system, and second, as that emergy embodied in services brought into the importing system. Though the effect of including imported human services in these two evaluations (or any of the evaluations in this study) was not significant, its presence may suggest a potential problem when services are estimated from dollar values.

The large renewable empower support for both the Union and Confederacy (Figure 3-10) emphasized the presence of large rural and agricultural areas in both systems. This common characteristic has often been overlooked (Moes, 1967). The Confederacy's low use of non-renewable empower (Figures 3-10 and 4-2) was indicative of its low state of industrialization and its limited railroad infrastructure. Though not explicitly recognized as non-renewable natural resource driven factors, the poor use of this limited industrialization and infrastructure has been cited as a contributing cause of the Confederate defeat (Current, 1960). The relatively large amount exported empower for the Union and Confederate systems was evidence of the large volume of trade between the two systems. This trade was recognized as large and important before the War (Kettell, 1860) and has been documented and studied since as an economic question (Fishlow, 1964; Lindstrom, 1970; Herbst, 1974). It is important to note that the amount of emergy

Great Britain imported was significantly larger than could be accounted for by the export of Confederate cotton to Great Britain (Figure 4-2 and Tables 3-17 and 3-19).

The changes in the empower support of the Confederate states during the War are probably evidence of the importance of the blockade and the labor and transportation difficulties the Confederacy faced. The increase in the emergy value of food imported into the Confederacy, in the form of animal products brought through the blockade (38-fold per year, Table 3-22), emphasized Wise's (1988) observation that the Army of Northern Virginia was largely supported by imports. The same can be said about the 14-fold increase per year in the emergy value of Confederate lead imports (Table 3-22) and about decreased mining.

The decrease in the emergy values of iron and copper extracted during the War (such that the extractions for the war period are less than for 1860 alone) may have been the result of: 1.) different reporting techniques used by the Federal and Confederate governments; 2.) Federal damage to or control over some of the mines; 3.) labor shortages at the mines; or 4.) the inability to transport the extracted product from the mines. Coulter (1950) suggested that South had the all the raw materials necessary to wage war and that many mines remained in Confederate territory until the end of the War. He overlooked the fact that some mines were located in east Tennessee, the mountains of the Carolinas and Georgia, or in other areas of Union sentiment where production for the Confederate war effort would have been slowed. Regardless, when compared to the Union, the emergy value of minerals and fossil fuel extracted by the Confederacy was much lower both before and during the War.

When Coulter maintained the Confederacy had ample resources with which to wage war, he based his judgment on the total, gross production of these resources while neglecting to consider both the maximum-power principle and the resource cost of bringing a resource to its final product state (in other words emergy). The maximum-power principle suggests that the optimal use of allocation of non-renewable resources in Confederate war production (e.g. munitions, weapons, and accouterments) would not have been the total amount of non-renewable resources available, but somewhere below the total amount. The maximum efficiency of war production (relative to raw materials) would have been achieved by allocating all non-renewable resources to war production. The total allocation of resources to production would have prevented their use in the processes that supported production and distribution, however. The lack of resources for support and distribution would have greatly slowed the rate at which war production was supplied to the armies. Thus, the optimum efficiency for war production was less than maximum, as suggested by general systems principles (Odum and Pinkerton, 1955; Odum, 1983). The entire production of minerals and fuel could not be applied to the war effort because a significant amount of the fuel and minerals was required for the production of additional fuels and minerals. Evidence of this was readily apparent in the performance of the Confederate railroads. While production of war materiel greatly increased (Vandiver, 1947), Southern railroads deteriorated (even where they were not destroyed by the armies) because replacement material was unavailable (Gates, 1965; McPherson, 1992).

This same principle may be seen in the law of diminishing returns. However, if the raw materials are not seen as necessary requirements for their own production, a different argument can be made. This argument would be that wartime demands could cause a system which produces something that aids the survival of the system at war, to operate beyond the break-even point (where the cost of production equaled the value of the product). The system would continue to operate beyond this break-even point because the product's real value is potentially infinite. This explanation is again based on a misconstrued concept of cost that neglects the natural resources required to take the produced war materiel and put it in action against the enemy. The law of diminishing returns is valid and can be applied to wartime production, but it must be in terms of resource requirements, i.e. emergy.

It was recognized during the War that the maximum length of a wagon-based supply line was about 100 miles because that was the distance a wagon could travel before the fodder required by its mules exceeded the load it could carry or deliver (Drury and Gibbons, 1993). This recognition was simply a question of energy if the wagon load and the fodder were the same, but the question required emergy techniques when the fodder (inputs) and load (outputs) were different.

Because these types of questions required emergy techniques, they may represent requirements or costs that were essentially hidden at the beginning of the Civil War. These "hidden requirements" may have been a significant factor in determining morale of both the troops and the home front. These sort of issues have been under-emphasized by many historians when addressing the potentials of the Confederacy and the Union in the same manner Young (1991) neglected resources as requirements (as discussed above).

Empower of the Civil War

The overall emergy use of the Civil War, relative to the emergy support of the U.S., offers an interesting perspective on the impact of the Civil War, particularly when viewed from afar. The sum of the emergy use and destruction of the Civil War was between 2.78E+23 sej and 5.95E+23 sej depending upon whether or not the unaccounted for human services estimates were included. This was between 1.3 and 2.7 times the annual emergy support of the United States as a whole in 1860 (Table 3-11). This sum of emergy or emergy impact of the War may be divided into two forms: 1.) the emergy of the *effort* required to wage war; and 2.) the *effect* of this war-waging emergy in damaging enemy troops, materiel, and resources. The effort required for the Union to wage the War (materiel, labor, fuel, vessels, and weapons) was between 7.13E+22 sej and 2.209E+23 sej. This was 1.8 to 5.6 times the damage incurred by the Union (deaths, disabilities, and destroyed vessels and materiel) and 0.70 to 2.0 times the effect on the Confederacy (damage inflicted in terms of deaths, disabilities, and destroyed vessels, property, and materiel) (Table 4-5). The effort required for the Confederacy to wage the War was between 5.47E+22 sej and 1.505E+23 sej, 0.51 to 5.6 times the damage incurred by the Confederacy and 1.5 to 4.1 times the damage inflicted on the Union (effect).

In the cases where the emergy value ratios of effort expended to effect (damage inflicted) are less than one, "unaccounted for Union human services" (term 19, Table 3-27) were not

Table 4-5. The emergy required to wage war verses the emergy of the war's destruction for the Union and Confederacy during the Civil War.

	Solar Emergy (1E20 sej)
Union Emergy Required to Wage War[a] (*Effort*) Materiel, Labor, Human Services, & Fuel	**739.3 to 2,235.3**
Emergy of Union Resource Destruction Caused by War[b] (*Effect*) Deaths & Disabling Injuries, & Lost Vessels	**368.7**
Ratio of Union War Requirements to Destruction of Confederate Resources[c] (Union *Effort* / Confederate *Effect*, Measured in Emergy) **0.70 - 2.0**	
Confederate Emergy Required to Wage War[d] (*Effort*) Materiel, Labor, Human Services, & Fuel	**547.4 to 1505.5**
Emergy of Confederate Resource Destruction Caused by War[e] (*Effect*) Deaths & Disabling Injuries, Lost Vessels, Destroyed Livestock, Equipment & Other Property	**1,128.9 to 1836.6**
Ratio of Confederate War Requirements to Destruction of Union Resources[f] (Confederate *Effort* / Union *Effect*, Measured in Emergy) **1.5 - 4.1**	

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[a] High value is the sum of terms 1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 14, 15, 18, and 19 (Table 3-27). Low value does not include term 19.

[b] Value is the sum of terms 9, 10, 13, 14, and 17 (Table 3-27).

[c] Ratios were calculated as the low and high Union effort values divided by the low Confederate effect value, respectively.

[d] High value is the sum of terms 20, 21, 22, 23, 24, 25, 26, 29, 30, 32, 33, 34, 36, and 37 (Table 3-27). Low value does not include term 37.

[e] Low value is the sum of terms 27, 28, 31, 32, 35, and 38 (Table 3-27). High value is the sum of terms 27, 28, 31, 32, 35, 39, 40, and 41 (Table 3-27).

[f] Ratios were calculated as the low and high Confederate effort values divided by the Union effect value.

included in the effort calculations. This potentially excluded large amounts of human labor embodied in war effort. Where these unaccounted for services were included, all ratios of effort expended to damage inflicted were much larger than one. The use of less conservative Union effort estimates may be justified because of the large logistical support of the Union forces. These ratios of effort to effect tentatively suggest a general principle that the emergy used to wage war is larger than the emergy value of the damage the war inflicts. Brown's (1977) evaluation of the Vietnam War supports this conclusion.

Some historians may consider the Reconstruction period that followed the United States Civil War to be continuation of the War, or at least an effect caused by the War that should be considered in this study's analysis of the War's effort and effect. The sectional strife that preceded the War could also be seen as an input or an effort necessary for the conflict to reach an actual state of outright war. Many historians have argued that the Civil War dramatically shaped U.S. history in the century that followed 1860. This influence could similarly be considered an effect of the War. All these considerations are the result of alternative boundaries for the systems being evaluated. These particular alternative boundaries are created by considering different scales of time, but the boundaries could be just as easily changed by considering different spatial scales. These and many other historical questions are strongly affected by questions of scale. That an historical emergy evaluation should raise questions of scale is not surprising, as the emergy technique owes much to ecology, a field that has recognized the theoretical implications of scales (Holling, 1992; Levin, 1992).

This question and problem of scale is not limited to the study of history. Historical events unfold around the scales historical figures and societies considered and chose when making their decisions, and the reasons they chose those scales. Thus, when secessionists of 1860 argued that the Confederacy had all the resources necessary to wage and win a war, they were considering a system whose boundaries only included the army and its requirements. They were neglecting the larger-scale system which included the processes and requirements of manufacturing and distribution (both material and labor), a system whose impoverishment lead to the downfall of the

Confederacy. Current policy makers face similar problems in determining scale. Young's (1991) discussion of natural resource scarcity is just as affected by the of scales he chose as the arguments of secessionists in 1860.

Emergies and Transformities of Battle

If battles, and particularly the net result of several battles, win or lose wars, then the emergy characteristics of battles should be important. Indeed, emergy indices may be able to provide new insights into factors like homefront morale that battles influence. The difference between the emergy values of the effort required to wage war and the effect this effort has in damaging resources was likely the result of the hierarchical organization of armies and navies. In this organization, only a small number of the total personnel actually fought the war. The rest served in support of the small number actually fighting. The presence of these support personnel increased the emergy required to wage war. But, the emergy of damage inflicted was directly proportional to the number of troops with the capacity to cause damage (those troops actually fighting), not the number of support personnel. Thus, the emergy of *effort* probably exceeded that of *effect* because of the maximum-power principle. To obtain *maximum efficiency* or effect, the number of support personnel would have to have been significantly reduced. But, reduction of support personnel limited the ability of an army to fight as quickly and intensively as it could at its *optimum efficiency.* It was the ability to fight quickly and intensively that enabled armies to win battles, and thereby wars. The Chinese military theorist Sun-tzu recognized this. Writing around 500 B.C., he said "thus the army values being victorious; it does not value prolonged warfare. Therefore, a general who understands warfare is Master of Fate for the people, ruler of the state's security or endangerment" (Sun-tzu, 1994, p. 174).

The great importance of the quantity and condition of the "front line" troops actually on the firing line, and in direct contact with the enemy has long been recognized in warfare (Von

Clausewitz, 1984). The quality and condition are largely dependent upon transportation and logistical support or supply of the troops. Because of this, the emergy required to place troops in contact with the enemy is an important measurement. The precise data needed to make such measurements for the Civil War were difficult to find. However, some evidence may be drawn from a brief discussion.

One reason the effort required to wage the Civil War was greater than the damage or effect caused by the War may have been the requirements for logistical support of front-line troops. Figure 4-5 highlights the important flows within a model of the Civil War that represent supply and logistics. The terms "unaccounted for human services" in Table 3-27 (terms 19 and 37) are primarily comprised of the labor of this logistical support. As an example, a typical Union army corps of 15,000 to 20,000 men required 600 to 800 wagons to maintain its supply line from the closest railhead or port. These wagons would occupy 5 miles of road. Each wagon was pulled by 6 mules and each wagon train required a complement of teamsters and blacksmiths to drive and maintain it as well as troops to guard it from enemy attack (Drury and Gibbons, 1993). The unaccounted for human services also represent the labor required to construct, maintain, and guard the railroads that supplied the wagon trains. The civilian Construction Corps consisted of 24,000 men at its peak and built bridges and laid track in what was then record time. Similarly, pioneer battalions were required to blaze roads and build bridges for troops and wagons. These facts support the use of the less conservative Union effort estimates. When the less conservative estimates are used, confidence in the observation that effort is greater than effect in war is strengthened.

Table 4-6 compares the transformities of several components of battles or warfare. The higher transformity human deaths dominated the emergy of the battle, while lower transformity components like gunpowder and horse labor contributed only small amounts of emergy. The battle evaluation suggested that the emergy used and destroyed in battle of Gettysburg was 0.70% of the emergy support of the U.S. in 1860, 1.5% of empower support of the Confederacy in 1860, and 1.0% of the and the Union in 1860. The battle of Gettysburg accounted for 0.70% to 2.1% of the

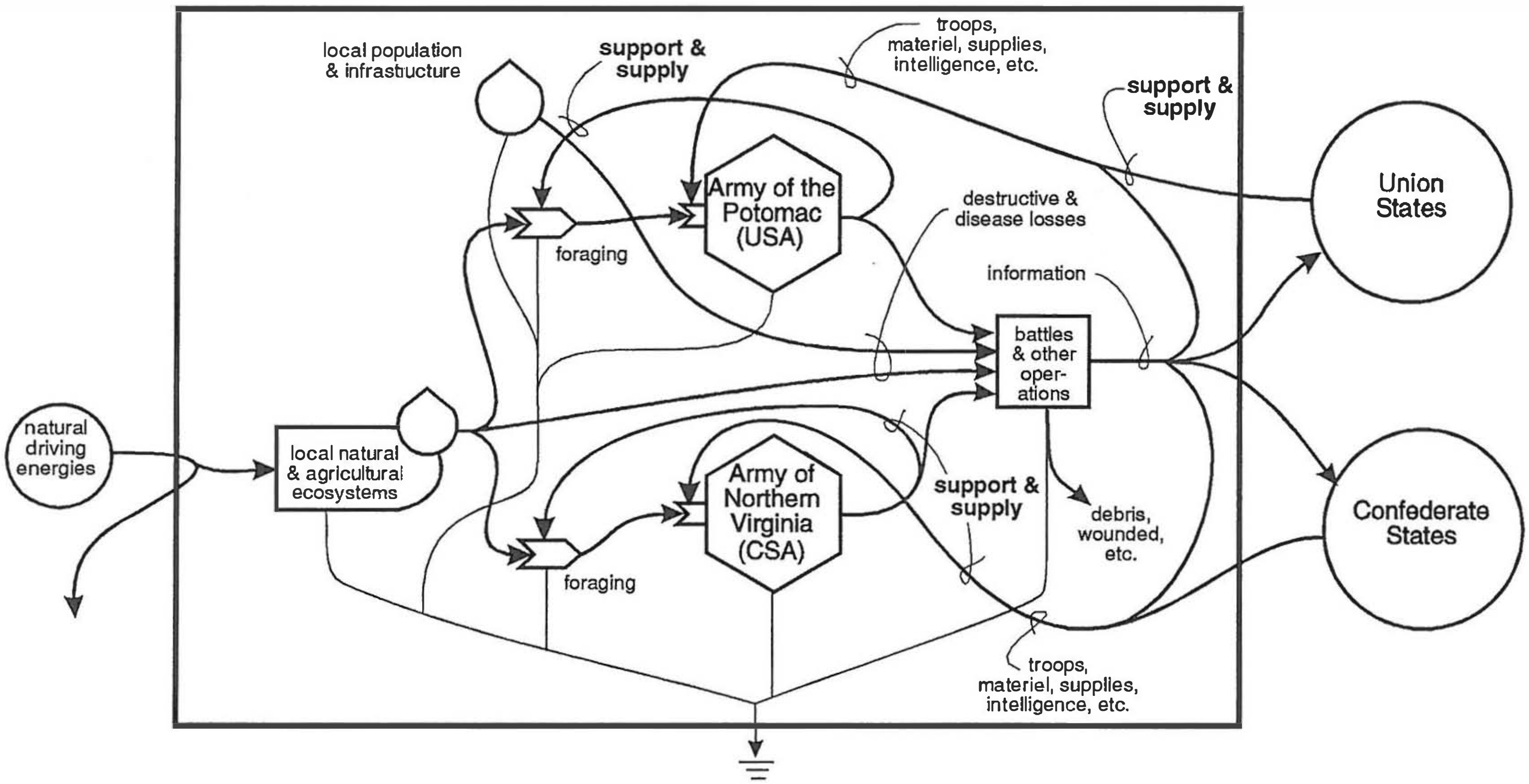

Figure 4-5. A generic model of a Civil War battle in the East.

Table 4-6. A comparison of transformities for the components of a battle.

component	transformity 1E+05 sej/J	source
Horse, labor	2	from Sundberg et al. (1994b)[a]
Gunpowder	20	Table 3-3
Soldier, labor	41	from Table 3-25[b]
Horse, killed	47	from Table 3-27[c]
Soldier, killed	2500	from Table 3-28[d]
Weapons (cannon & rifles)	6500	from Table 3-5
Lead (minie balls)	7200	from Table 3-4[e]

[a] Using an average daily labor output of a horse of 1.0E+07 J/horse-day.

[b] Using a daily human labor output of 5.0E+06 J/person-day.

[c] Using 4.74E+08 J/horse as the energy value of the average horse's body and the transformity used in term 16, Table 3-27.

[d] Using 4.47E+08 J/person as the energy value of the average soldier's body and the transformity used in term 11, Table 3-28.

[e] Using an estimated free energy value of 12.6 J/g.

entire emergy of the Civil War. The evaluation technique used for the battle was quite similar to that used to generate the 739.3E+20 sej estimate for the emergy of the Civil War (Table 4-5). Because of this, the estimate for the emergy of Gettysburg as 2.1% of the Civil War was the most accurate.

Comparisons of the Civil War and Other Wars

Just as emergy indices allow the comparison of different systems at different times, so to do they allow the comparison of different events in different periods, in this case wars. A comparison of the emergy characteristics of the Civil War, the Vietnam War and the wars of the seventeenth-century Swedish Empire is given in Table 4-7. The emergy (9.977E+23 sej) required for both sides to wage the Vietnam War was 5.7 times the emergy (1.923E+23 sej) of damage inflicted during the War. As in the Civil War, the emergy required to wage war or inflict damage (effort) in the Vietnam War was greater than the damage inflicted (effect). However, the 5.7 to 1 ratio between effort and effect for the Vietnam War was higher than the 1.7 to 1 average for the Civil War (Table 4-8). The effort-effect ratio of the Persian Gulf War (Table 4-9) was midway between the ratios for the Civil War and the Vietnam War. This may be attributable to the Gulf War being more of a conventional war with large, concentrated armies facing one another as opposed to a guerrilla war like Vietnam that was organized around smaller, more dispersed forces. The effort/effect ratio can also be said to express the effect of a war on the homefront verses the effect (effort) on the warfront. The effort from the homefront is the labor, energy, and material used to supply the army. The effort on the warfront is the deaths and damages that directly result from the war. Deaths, even of an enemy, are a problem because of the danger of disease from corpses (McPherson, 1992).

In some civil wars, the homefront and warfront are the same. That the Confederacy suffered this problem is commonly accepted. That this problem was a necessary product of the

Table 4-7. A comparison of the emergy of the requirements, flows, and destruction of storages during the United States Civil War, the Vietnam War , and the wars of the seventeenth-century Swedish Empire.

Item	Solar Emergy[a] (1E20 sej)	
U.S. Civil War[b]		
Union Materiel	26.3	
Union Labor of Troops & Sailors	343.	
Union Deaths & Disabling Injuries	362.9	
Union Fuel Use	256.	
Union Vessels	89.0	
Lost Union Merchant Vessels	5.82	
Union Civil Servants	24.9	
Unaccounted for Union Human Services	1496.	
Union Total[c] =	**1108. to 2604.**	
Confederate Materiel	12.2	
Confederate Labor of Troops & Sailors	406.5	
Confederate Deaths & Disabling Injuries	483.1	
Confederate Fuel Use	10.9	
Confederate Vessels	89.0	
Lost Confederate Blockade Running Vessels	78.5	
Confederate Civil Servants	29.1	
Unaccounted for Confederate Human Services	958	
Confederate Total[d] =	**1109. to 2067.**	
Damages to Confederate Livestock, Equipment, & Property[e]	567.3 to 1275.	
Total War Impact[f] =	**2784. to 5946.**	
Vietnam War[g](1965-1973)		
Vietnamese Causalities, Wounded	53.	
Vietnamese Causalities, Deaths	1080.	
U.S. Causalities, Wounded	150.	
U.S. Causalities, Deaths	270.	
Total Casualties	1553.	
Direct U.S. War Costs (Goods and Services)	9130.	
U.S. Aid to Vietnam (Goods and Services)	200.	
Communist War Costs (Goods and Services)	250.	
Fuels Used	130.	
Munitions	1160.	
Environmental Impact	370.	
Total Impact to Vietnam =	**1500.**	**(4 year impact = 750)**
Total U.S. Military Use =	**11900.**	**(4 year use = 5950)**
Swedish Empire Wars[h] (an average 4 year period from 1660 to 1720)		
Money from Sweden & France	0.0408	
Bronze Cannon	0.0408	
Iron Cannon & Horse Shoes	0.00816	
Horses	0.339	
Ships	1.44	
Naval Weapons	0.126	
Soldiers	14.3	
Supplies from Occupied Lands	7.44	
Total use from 1660 to 1720 =	**1142.**	**(4 year use = 23.7)**

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[a] The high or low values for different wars were not calculated using the same assumptions.

[c] United States Civil War data are from Table 3-27.

[c] High and low Union totals are calculated with and without unaccounted for Union human services respectively.

[d] High and low Confederate totals are calculated with and without unaccounted for Confederate human services respectively.

[e] High and low values are calculated with and without the estimate from term 38, Table 3-27.

[f] High and low values are calculated using high and low Union and Confederate totals and property losses respectively.

[g] Vietnam War data are from Brown (1977) (adjusted by H.T. Odum ("Emergy and Public Policy: Part III." Unpublished Manuscript. University of Florida Center for Environmental Policy. Gainesville, FL)).

[h] Swedish Empire wars data are from Sundberg et al. (1994a).

Table 4-8. The emergy required to wage war verses the emergy of the war's destruction for the Civil War and the Vietnam War.

	Solar Emergy (1E20 sej)
U.S. Civil War (1861-1864)	
Emergy Required to Wage War (*Effort*) Materiel, Labor, Human Services, & Fuel	**1,260.1 to 3,714.4**
Emergy of Destruction Caused by War (*Effect*) Deaths & Disabling Injuries, Lost Vessels, Destroyed Livestock, Equipment & Other Property	**1,523.9 to 2,231.6**
Ratio of War Requirements to Destruction (*Effort/Effect*, Measured in Emergy) **0.83 - 1.7**	
Vietnam War (1965-1973)	
Emergy Required to Wage War (*Effort*) Materiel, Human Services, & Fuel	**10,870**
Emergy of Destruction Caused by War (*Effect*) Deaths & Disabling Injuries, & Environmental Impact	**1,920**
Ratio of War Requirements to Destruction (*Effort/Effect*, Measured in Emergy) **5.7**	

Table 4-9. The emergy required to wage war verses the emergy of the war's destruction for the Civil War and the Persian Gulf War.

	Solar Emergy (1E20 sej)
U.S. Civil War (1861-1864)	
Emergy Required to Wage War (*Effort*) Materiel, Labor, Human Services, & Fuel	**1,260.1 to 3,714.4**
Emergy of Destruction Caused by War (*Effect*) Deaths & Disabling Injuries, Lost Vessels, Destroyed Livestock, Equipment & Other Property	**1,523.9 to 2,231.6**
Ratio of War Requirements to Destruction (*Effort/Effect*, Measured in Emergy) **0.83 - 1.7**	
Persian Gulf War[a] (1990-1991)	
Emergy Required to Wage War (*Effort*) Materiel, Human Services, & Fuel	**5,924**
Emergy of Destruction Caused by War[b] (*Effect*) Deaths & Disabling Injuries, & Environmental Impact	**1,579 to 4,109**
Ratio of War Requirements to Destruction (*Effort/Effect*, Measured in Emergy) **1.4 - 3.8**	

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[a] Data were adjusted from a preliminary evaluation by H.T. Odum ("Emergy and Public Policy: Part III." Unpublished Manuscript. University of Florida Center for Environmental Policy. Gainesville, FL) to correspond with the evaluation techniques used for the Civil War.

[b] The higher estimate included the emergy value of oil destroyed in oil wells that continued to burn after the War was over. The lower estimate excluded this value.

Confederacy's fighting a defensive war is less discussed. Beringer et al. (1986) discussed at length the advantages the Confederacy gained by fighting a defensive war. But, they measured these advantages in terms causalities and immediate military success. These were direct costs or requirements. Indirect costs or requirements like damages to farmland and railroads were excluded from their analysis, even though these damages where important factors in the overall Confederate defeat. However, without a tool like emergy that can apply a single measure to all requirements, it is impossible to compare direct and indirect requirements.

A comparison of the wars (Tables 4-7 and 4-10) shows the marked change in the intensity of waging war from the seventeenth to the twentieth century. The total emergy requirement (total inputs and damages) of 60 years of war in the Swedish Empire was 20% of the emergy value of 4 years of the Civil War. The Vietnam War lasted 8 years and had a total emergy requirement twice that of the Civil War. While U.S. troop involvement in the Vietnam War was considerably less than that of the Civil War, the 1,709,000 total Vietnamese military and civilian deaths of the Vietnam War (Brown, 1977) significantly exceed the 600,000 military Civil War deaths (Livermore, 1900). This similarity between the emergy requirements of the Civil War and Vietnam War and their differences compared with the Swedish Empire Wars strongly support the contention that the Civil War was one of the first "modern wars," a point still discussed by Civil War historians (McPherson, 1992).

The question of scale arises again when comparing different wars. For instance, the labor and weapons of the Persian Gulf War could be considered requirements for Cold War military operations. Under these considerations, the weapons and labor would not have been put to productive use even if the Persian Gulf War had not occurred. These conditions simply create a different conceptual model for the Gulf War evaluation by using larger temporal and spatial scales. Eliminating these inputs to the Gulf War significantly change the evaluation's results, decreasing the effort/effect ratio.

Table 4-10. Comparisons of the effort-effect ratios for the Civil War, the Vietnam War, and the Persian Gulf War.

	Effort/Effect **Measured in Emergy**
United States Civil War[a]	**0.83 - 1.7**
Vietnam War[b]	**5.7**
Persian Gulf War[c]	**1.4 - 3.8**

[a] Table 4-5.
[b] Table 4-8.
[c] Table 4-9.

Emergy and Emancipation: The United States Slave System

The transformity of an individual slave might be estimated at 16 times his or her annual empower support (for 16 years of maturation processes) giving a transformity value of 1.44E+17 sej/person (using the 9.0E+15 sej/person-year from Table 3-18). If enslaved children are assumed to have had transformities half those of enslaved adults (2 children equal 1 adult-equivalent), there were 3 million adult-equivalent slaves in 1860. Using the transformity estimated above, these people would have embodied a total emergy of 4.32E+23 sej. This was almost 3 times the annual empower support of the entire U.S. in 1860 (Table 3-11) and approximately the emergy value estimated for the requirements, inputs, and damages for the entire Civil War. Similar ratios could be drawn from simple comparisons of population, but the argument seems more forceful when made in terms of the potential contributions of enslaved individuals (emergy) or the resources required to support these individuals (emergy) rather than their simple existence (population).

The large value of the emergy embodied in enslaved people may suggest why the issue of slavery was significant in the nineteenth-century U.S. The emergy embodied in these enslaved people represented a huge potential. In 1860, it was believed that this potential would allow slave owners to exploit new natural resources and out compete small, Northern yeoman farmers (Free-soilers) for the new lands in the West. If slaves were freed, the same emergy that was a threat to the Northern, yeoman farmers would have been seen as a competitive threat by the Southern yeoman farmers who would fear their competiton for resources. Finally, the loss of the emergy embodied in slaves would have destroyed the plantation owners. The system of sharecropping that developed after the Civil War might be seen as having allowed the plantation operators to maintain control of the emergy embodied in former slaves through means other than direct ownership.

The Civil War and the Pulsing Paradigm

The pulsing paradigm of systems (as opposed to a steady-state paradigm) is widely recognized in ecology and general systems (Odum, 1983; 1987a; Odum et al., 1993). Under this paradigm, systems do not operate steadily, but undergo pulsed periods of production and decomposition in strategies that maximize the overall functioning of the systems. A simple example is a fire dominated forest system where periods of growth are interrupted by periods of destructive fires. These fires serve to speed the cycling of nutrients, decrease competition between species, and spur seed germination.

A pulsing paradigm has long been recognized in military theory under different concepts or names than "pulsing." As early as 500 B.C., the Chinese military theorist Sun-tzu recognized that the goal of war was not prolonged conflict but rapid, pulsing victories (Sun-tzu, 1994). By the 1830s, Clausewitz had cited several reasons why the presence of two competing armies or systems in war made war a pulsing rather than a steady-state function. He stated that "action in war is not continuous but spasmodic. Violent clashes are interrupted by periods of observation during which both sides are on the defensive" (Von Clausewitz, 1984, p.219).

The evaluations in this study provided evidence on the magnitude of pulsing in war. The battle of Gettysburg accounted for approximately 2% of the emergy use and destruction during the Civil War. Measured in time, the three-day battle accounted for only 0.60% of the 4 years of the War. Thus, the emergy impact of the battle was 3 times more than would have been expected if the War was a steady-state event rather than a pulsing event.

Emergy and History: What This Study Suggests

Though the United States Civil War may have had its root in ideological concerns, it was not independent of natural resources and nature's work. The ideology of a society supported by natural resources is itself supported by these resources even when the ideology fails to consider resources. The debate about slavery that dominated the decades preceding the Civil War may have centered on moral and economic concerns, but the fact that agriculture was the predominate employment slaves made it just as much a debate about the mechanism used to harvest or capture renewable resources. The overwhelming importance of renewable resources to the nineteenth-century U.S. that this study found highlights the reasons a debate over renewable resource harvest mechanism would become an important issue. This overwhelming importance is all more important to recall when trying to understand the Civil War from a late twentieth century perspective, as the support basis of the U.S. becomes increasingly distant from that which existed in 1860.

The importance of renewable resources to the 1860 United States is also significant when considering the effect of labor shortages in the Confederacy. The South was even more dependent on renewable resources than the U.S. as a whole. Its harvest of these resources was diminished by labor and draft animal shortages, the incursions of armies, slaves escaping to areas of Union control, and even a drought. In a system that made more use of non-renewable resources, fossil fuel storages could have been used to substitute machinery for human labor and draft animals or pump water to compensate for the drought. But, a system dominated by renewable resources had fewer storages to buffer the effects of war and thereby buffer the effect on troop and homefront morale.

This is not to suggest that only historians can misinterpret the importance of resources or that only renewable resources were important in the Civil War. An outdated or incomplete understanding of natural resources and resource use may have contributed to the outbreak of war just as outdated concepts and theories of warfare contributed to the high death tolls of the Civil War. On the eve of the war, many Southerners believed the Confederacy could successfully wage a war against the Union. The United States in 1860 was largely an agricultural society, and the industrialization that had occurred, occurred recently. Thus, U.S. society may have continued to view agricultural capacity as an important contributor to wealth and resources.

The Confederacy's decision to go to war is better justified if agriculture is used a basis to compare the North and South. Sundberg et al. (1994a, 1994b) evaluated seventeenth century wars that "feed themselves" where agricultural production was an important component of victory Indeed, 1860 Northern free-soilers feared Southern slave owners because of a belief that the wealth of slave owners would be able to outbid small farmers for newly opened lands in the West. Thus the North actually feared the agricultural might of the South, a fear which could have bolstered Southern confidence. Evidence to support the idea that outdated perceptions of resources helped carry the people of the U.S. into a civil war can be found in the reliance on eighteenth century tactics in the face of twentieth century weapons. This reliance characterized much of the Civil War and was the cause of heavy causalities.

An incomplete understanding of resource costs or requirements may have also contributed to the South's belief it could win a war against the North. This incomplete understanding of resource use would have viewed resource requirements or costs as only the materials, fuel, and labor directly used in producing war materiel, instead of the total of materials, fuel, and labor used to secure and refine raw materials and to support the labor. This incomplete view would have resulted in requirements or costs that were essentially hidden at the beginning of the Civil War. These "hidden requirements" would have become more apparent as the War progressed and could then have become a significant factor in undermining the morale of both the troops and the home front. In short the additive or even autocatalytic effect of these misconceptions and hidden costs could have been easily translated into the Confederacy's loss of will to fight.

This study provided several pieces of evidence that suggest that emergy evaluation describes and can describe or predict the success of human efforts. The study did not intend to argue that emergy evaluation can support an independent field of historical study as emergy cannot be independent of other historical fields because it depends heavily on their analyses and interpretations for its own raw data. The Swedish historian Jan Lindegren similarly concluded that while emergy evaluation had a huge potential for historical studies, the technique would not truly revolutionize the study of historical events (Sundberg et al., 1994a). He suggested that emergy suffers from some of the same problems as other methods of quantitative historical study. However, just as with other quantitative methods, emergy evaluation offers the opportunity to sift through and explore historical evidence with a new filter and offers the opportunity for new insights.

One of the significant features of this study was its ability to produce results that agreed with accepted hypotheses of economic history, like the Cochran thesis of United States industrialization, without using economic techniques. This has important implications for environmental policy studies as it is evidence that emergy evaluation techniques can predict or at least describe the economic processes of human systems. Part of the reason emergy results agreed with economic concepts for the nineteenth century may have been that incomplete nineteenth-century data sets forced economic historians to go beyond economic evaluation techniques and rely more heavily than usual on intuitive interpretations of natural resource use.

The transformity calculations in this study showed that the production of war supplies and materiel requires far more than simply human labor. Any truly quantitative historical effort that attempts to analyze inputs that are of different forms greatly benefits from a method like emergy that can measure the inputs on a common basis. The observation that the emergy of effort invested in waging war exceeds that of the destruction of war could have only been made with a technique like emergy evaluation. This observation has the potential to provide important insights into the study of warfare and perhaps other processes that are considered to be analogs of war.

The comparison of prices and emergy indices of 1870 and 1980 showed the drastic changes personal income and gross national product underwent in the 110 year period and the reason prices and personal income do not provide adequate means to compare the two periods. Emergy, on the other hand, allows not only the comparison of these two periods, but of different countries in different years and of the purchasing power of income in different years. Because the units of emergy are constant (measuring the same value even in different years), emergy is an easier and more straightforward way to express historical values than current dollars and constant dollars.

The study's ability to analyze, discuss, and compare different kinds of costs and requirements suggest the potential value of emergy in the social sciences. This ability makes emergy evaluation an important tool for future policy formulation as well. The evidence from this study that suggests emergy evaluation can track and predict human success and well being is important support for the argument that emergy evaluation is a justified tool in the development of environmental policies.

APPENDIX A
ENERGY AND MASS CONVERSIONS USED IN THIS STUDY

Material	Conversion	Units	Source
coal	2.2E+13	J/Mg	Shonka (1979)
crude oil	6.1E+09	J/bbl	Shonka (1979)
flour	45360	g/bag	FAO (1972)
grain (unspecified or mixed)	27220	g/bushel	FAO (1972)
invertebrate biomass	16700	J/g-dry wt	estimated from Odum (1969)
plant biomass	16700	J/g-dry wt	estimated from Odum (1969)
timber, uncured	0.90	g/cm^3	estimated from FAO (1980)
timber	0.20	g-dry wt/g-uncured wt	estimated from FAO (1980)
vertebrate biomass	0.30	g-dry wt/g-live wt	Carter (1969)
vertebrate biomass	29000	J/g-dry wt	estimated from Odum (1969)
cotton	1.62E+06	g/bale	assumed
iron, metal	16.2	J/g	estimated from Odum (1994)

APPENDIX B
CALCULATIONS IN SUPPORT OF TABLE 3-6, EMERGY EVALUATION OF THE UNITED STATES IN 1850.

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term:

1 SOLAR ENERGY:

Effective continental shelf area, 1850 = 2.0E+15 m^2 (assumed as 28% of actual shelf area)
Farm area 1850 = 1.2E+12 m^2 (estimated from USDC (1975))
Insolation = 4.6E+09 $J/m^2/y$ (estimated from Kung et al. (1964))
Albedo = 0.53 (estimated from Kung et al. (1964))
Energy = ((land area) + (shelf area))m^2 * (avg. insolation) J/m^2-y * (1-albedo)
Energy = 4.2E+21 J/y

2 WIND, KINETIC ENERGY

Wind energy = 2.3E+19 J/y (estimated from Odum et al. (1987a) for the land area in farms in 1850 (USCO, 1854))

3 RAIN, GEOPOTENTIAL ENERGY:

Farm area 1850 = 1.2E+16 cm^2 (from USCO (1854))
Rainfall = 1.1E+02 cm (estimated from NOAA (1977))
Average elevation = 4.6E+04 cm (estimated)
Runoff rate = 8.0E-01 % (estimated)
Water density = 1.0E+00 g/cm^2
Gravitational constant = 9.8E+02 cm/s^2
Energy = (area) cm^2 * (runoff rate) * (rainfall) cm * (avg. elevation) cm * (water density) g/cm^3 * (gravitational constant) cm/s^2 * 9.96E-08 J/erg
Energy = 4.9E+18 J/y

4 RAIN, CHEMICAL POTENTIAL ENERGY:

Farm area 1850 = 1.2E+12 m^2 (estimated from USCO (1854))
Effective continental shelf area, 1850 = 2.0E+11 m^2 (assumed as 28% of actual shelf area)
Rainfall = 1.1E+00 m/y (estimated from NOAA (1977))
Rain over shelf = 1.0E+00 m/y (estimated from NOAA (1977))
Evapotranspiration rate = 5.0E-01 (percent given as decimal) (estimated)
Water density = 1.0E+03 kg/m^3
Gibbs free energy = 4.9E+03 J/kg
Energy over land = (area) m^2 * (Evapotranspiration) * (rainfall) m * (water density) kg/m^3 * (Gibbs free energy) J/kg
Energy = 3.3E+18 J/y
Energy over shelf = (area) m^2 * (rainfall) m * (water density) kg/m^2 * (Gibbs free energy) J/kg
Energy = 1.1E+18 J/y
Total energy = 4.4E+18 J/y

5 TIDAL ENERGY:

Effective continental shelf area, 1850 = 2.0E+15 cm^2 (assumed as 30% of actual shelf area)
Mean Tidal Range = 1.2E+02 cm (estimated from USCGS (1956))
Density = 1.0 g/cm^2
Number tides/y = 7.1E+02 (estimated from Odum et al. (1987a))
Absorption coefficient = 0.50 (assumed)
Gravitational constant = 980 cm/s^2
Energy = (shelf area) cm^2 * (absorption coeff.) * (0.5) * (tides/y) * (mean tidal range)^2 $(cm)^2$ *(sea water density) g/cm^3 * (gravitational constant) cm/s^3 * 9.96E-08 J/erg
Energy = 5.0E+17 J/y

6 WAVES:

Energy = 2.5E+18 J/y (estimated as 33% of Odum et al. (1987a))

7 EARTH CYCLE:
Land area 1850 = 1.2E+12 m^2 (estimated from USDC (1975))
Heat flow / area = % area stable * heat + % area active * heat flow $J/m^2/y$
Heat flow/area = 1.1E+06 J/m^2-y (estimated from Odum et al. (1987a))
Energy = (Land area) m^2 (Heat flow per unit area) J/m^2-y
Energy = 1.3E+18 J/y

8 FORESTRY:
1849 harvest 1.2E+13 g/y (estimated from Steers (1948))
1849 energy of harvest = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.70 g-dry/g-wet (assumed)
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1849 energy of harvest = 1.3E+17 J/y

9 FUELWOOD USE:
1850 use = 2.4E+18 J/y (USDC, 1975)

10 HYDROPOWER:
1850 Hydro-power = 1.7E+16 J/y (estimated from USCO (1874))

11 PLANT LEAF, FIBER, & PRODUCTS
1850 Hay = 1.3E+13 g/y (USCO, 1854)
1850 Flax = 3.5E+09 g/y (USCO, 1854)
1850 Hemp, dewrotted = 3.0E+10 g/y (USCO, 1854)
waterrotted = 1.5E+09 g/y (USCO, 1854)
1850 Tobacco = 9.1E+10 g/y(USCO, 1854)
1850 total production = 1.3E+13 g/y
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1850 energy of production = 1.8E+17 J/y

12 BREADSTUFFS & GRAINS
1850 Barley = 1.2E+11 g/y (USCO, 1854)
1850 Buckwheat = 2.0E+11 g/y (USCO, 1854)
1850 Clover seed = 1.3E+10 g/y (USCO, 1854)
1850 Flaxseed = 1.4E+10 g/y(USCO, 1854)
1850 Grass seeds = 9.5E+09 g/y (USCO, 1854)
1850 Indian corn = 1.5E+13 g/y (USCO, 1854)
1850 Oats = 2.5E+12 g/y (USCO, 1854)
1850 Peas & beans = 2.5E+11 g/y (USCO, 1854)
1850 Rice = 9.8E+10 g/y (USCO, 1854)
1850 Rye = 3.6E+11 g/y (USCO, 1854)
1850 Wheat = 4.7E+12 g/y (USCO, 1854)
1850 total production = 2.3E+13 g/y
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1850 energy of production = 3.6E+17 J/y

13 FRUIT & ROOT CROPS
1850 Hops = 1.6E+09 g/y (USCO, 1854)
1850 Irish potatoes = 1.8E+12 g/y (USCO, 1854)
1850 Sweet potatoes = 8.7E+11 g/y (USCO, 1854)
1850 total production = 2.7E+12 g/y
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 2.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1850 energy of prod. = 1.1E+16 J/y

14 GINNED COTTON
1850 production 5.5E+11 g/y(USCO, 1854)
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1850 energy of production = 8.0E+15 J/y

15 SUGAR & MOLASSES
1850 molasses = 6.8E+10 g/y (estimated from USCO (1854))
1850 Cane sugar = 1.1E+11 g/y(USCO, 1854)
1850 Maple sugar = 1.8E+10 g/y (USCO, 1854)
1850 total production = 1.9E+11 g/y
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1850 energy of prod. = 2.5E+15 J/y

16 SHELLFISH FISHERIES:
1850 shellfish catch = 2.4E+09 g/y (estimated from USCO (1854))
g-dry/g-live = 2.6E-01 g-dry/g-live (estimated from NRC (1971))
J/g-dry = 2.1E+04 J/g-dry (estimated from Odum (1969))
Energy of 1850 shellfish catch = (catch)g-live wt * (g-dry/g-live) * (J/g-dry)
Energy of catch = 1.3E+13 J/y

17 BUTTER & CHEESE
1850 Butter = 1.4E+11 g/y(USCO, 1854)
1850 Cheese = 4.8E+10 g/y (USCO, 1854)
1850 total production = 1.9E+11 g/y
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.75 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 3.3E+04 J/g (estimated from Odum (1969))
1850 energy of prod. = 4.8E+15 J/y

18 FINFISH FISHERIES:
1850 fish catch = 1.5E+11 g/y (estimated from USCO (1854))
g-dry/g-live = 2.6E-01 g-dry/g-live (estimated from NRC (1971))
J/g-dry = 2.1E+04 J/g-dry (estimated from Odum (1969))
Energy of 1850 fish catch = (catch)g-live wt * (g-dry/g-live) * (J/g-dry)
Energy of catch = 8.2E+14 J/y

19 LIVESTOCK PRODUCTION:
1850 cattle prod.= 2.8E+11 g/y (estimated from USCO (1854))
1850 swine prod.= 4.6E+11 g/y (estimated from USCO (1854))
1850 sheep prod.= 7.9E+10 g/y (estimated from USCO (1854))
1850 horse prod.= 2.2E+11 g/y (estimated from USCO (1854))
1850 mule prod.= 2.8E+10 g/y (estimated from USCO (1854))
1850 total prod.= 1.1E+12 g/y
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/ g = 2.1E+04 J/g (estimated from Odum (1969))
1850 energy of production = 6.6E+15 J/y

20 WOOL
1850 Wool = 2.4E+10 g/y (USCO, 1854)
1850 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1850 energy of prod. = 3.8E+14 J/y

21 SOIL LOSS
1850 improved farm land = 4.6E+07 ha (USCO, 1854)
Soil loss / improved ha = 1.5E+07 g/ha-y (estimated)
1850 total soil loss = 6.9E+14 g/y
Energy in soil loss = (Total loss) g/y * (% Organic matter) *(Energy/g organic matter) J/g * (dry weight/wet weight) g/g
% Organic matter = 3.3E+00 % (estimated from Brady (1990))
Energy/g organic matter = 2.3E+04 J/g (estimated)
Dry weight/wet weight = 5.0E-01 g-dry/g-wet (estimated)
1850 energy in soil loss = 2.5E+17 J/y

22	COAL			
		1850 extraction		
		bituminous =	1.1E+17	J/y (USDC, 1975)
		anthracite =	1.2E+17	J/y (USDC, 1975)
		total =	2.3E+17	J/y
23	IRON ORE	1850 extraction =	1.6E+12	g/y (Rothwell, 1892)
24	The transformity is a weighted average of the metals in this calculation.			
	COPPER , recovered	1850 extraction =	7.4E+08	g/y (Rothwell, 1892)
	LEAD, refined	1850 extraction =	2.0E+10	g/y (Rothwell, 1892)
	MERCURY	1850 extraction =	8.3E+08	g/y (Rothwell, 1892)
	SILVER:	1850 extraction	1.2E+06	g/y (from Rothwell (1892))
25	GOLD:	1850 extraction	7.5E+07	g/y (from Rothwell (1892))
26	The transformity is a weighted average of the plant products in this calculation.			
	FRUITS, GREEN, RIPE OR DRIED			
		currants	1.5E+09	g/y (USTD, 1852)
		dates	2.1E+08	g/y (USTD, 1852)
		figs	1.6E+09	g/y (USTD, 1852)
		plums	1.4E+06	g/y (USTD, 1852)
		raisins	8.3E+09	g/y (USTD, 1852)
		Total 1850 import =	1.2E+10	g/y
		1850 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
		dry-wt/wet-wt =	.050	g dry/g wet (estimated from Crampton & Harris (1969))
		energy/g =	1.7E+04	J/g (estimated from Odum (1969))
		18560 energy of import =	9.8E+13	J/y
	PLANT LEAF, BARK, & FIBER & INSECT PRODUCTS			
		Indigo	4.6E+08	g/y (estimated from USTD (1852))
		almonds	3.4E+09	g/y (estimated from USTD (1852))
		Spices		
		cassia	4.7E+08	g/y (estimated from USTD (1852))
		cinnamon	2.4E+07	g/y (estimated from USTD (1852))
		cloves	1.3E+08	g/y (estimated from USTD (1852))
		ginger, ground	4.6E+08	g/y (estimated from USTD (1852))
		dried, green, etc.	6.3E+06	g/y (estimated from USTD (1852))
		mace	6.3E+06	g/y (estimated from USTD (1852))
		nutmegs	1.8E+08	g/y (estimated from USTD (1852))
		pepper, red	3.5E+07	g/y (estimated from USTD (1852))
		black	2.5E+09	g/y (estimated from USTD (1852))
		pimento	5.3E+08	g/y (estimated from USTD (1852))
		Cordage, tarred and cables	2.9E+08	g/y (estimated from USTD (1852))
		un-tarred	1.3E+09	g/y (estimated from USTD (1852))
		Tea	2.5E+09	g/y (estimated from USTD (1852))
		Coffee	6.9E+10	g/y (estimated from USTD (1852))
		Total 1850 import =	8.1E+10	g/y
		1850 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
		dry-wt/wet-wt =	8.5E-01	g dry/g wet (estimated from Crampton & Harris (1969))
		energy/g =	1.7E+04	J/g (estimated from Odum (1969))
		1850 energy of import =	1.2E+15	J/y
	SUGAR			
		brown	1.6E+11	g/y (estimated from USTD (1852))
		candy	9.7E+06	g/y (estimated from USTD (1852))
		loafed & other refined	5.5E+09	g/y (estimated from USTD (1852))
		syrup of sugar cane	1.2E+05	g/y (estimated from USTD (1852))
		white, clayed, or powdered	2.2E+09	g/y (estimated from USTD (1852))
		Molasses	1.2E+11	
		Total 1850 import =	2.9E+11	g/y
		1850 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
		dry-wt/wet-wt =	0.90	g dry/g wet (estimated from Crampton & Harris (1969))
		energy/g =	1.7E+04	J/g (estimated from Odum (1969))
		1850 energy of import =	4.4E+15	J/y
27	COAL	1850 import =	6.0E+15	J/y (estimated from USTD (1852))

28 FISH, DRIED, SMOKED OR PICKLED

dried or smoked	6.7E+08	g/y (estimated from USTD (1852))
herring	2.0E+09	g/y (estimated from USTD (1852))
mackerel	9.3E+09	g/y (estimated from USTD (1852))
salmon	7.2E+08	g/y (estimated from USTD (1852))
all other	1.9E+09	g/y (estimated from USTD (1852))
1850 total =	1.5E+10	g/y

1850 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	0.30	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1850 energy in imports =	9.1E+13	J/y

29 WHALE PRODUCTS OF OFFSHORE & FOREIGN FISHERIES

whale oils	2.6E+10	g/y (estimated from USTD (1852))
sperm oil	4.0E+08	g/y (estimated from USTD (1852))
whale oil	3.1E+08	g/y (estimated from USTD (1852))
whale bone	2.5E+08	g/y (estimated from USTD (1852))
Total import & landing =	2.7E+10	g/y

1850 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	3.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1850 energy in imports =	1.7E+14	J/y

30 PLANT DERIVED ASH & SODA

Barilla	1.8E+10	g/y (USTD, 1852)
Soda, ash	1.8E+10	g/y (USTD, 1852)
1850 total import =	3.6E+10	g/y

31 IRON, STEEL, & MANUFACTURES OF

bar iron	2.5E+11	g/y (USTD, 1852)
hoop iron	6.6E+09	g/y (USTD, 1852)
nails, spikes, & tacks	1.9E+09	g/y (USTD, 1852)
old & scrap	7.6E+09	g/y (USTD, 1852)
pig	6.1E+10	g/y (USTD, 1852)
sheet iron	1.5E+10	g/y (USTD, 1852)
steel	7.3E+09	g/y (USTD, 1852)
wire, cap & bonnet	1.2E+09	g/y (USTD, 1852)
cables, chain	5.1E+09	g/y (USTD, 1852)
anchors & anchor parts	2.5E+08	g/y (USTD, 1852)
anvils & anvil parts	5.1E+08	g/y (USTD, 1852)
total import =	3.6E+11	g/y

32 The transformity is a weighted average of the materials in this calculation.

CHLORIDE OF LIME 1850 import = 2.4E+09 g/y (USTD, 1852)

LEAD & MANUFACTURES OF

bar, pig, sheet, & old	2.0E+10	g/y (USTD, 1852)
pipes	3.7E+06	g/y (USTD, 1852)
shot	7.3E+07	g/y (USTD, 1852)
Total import =	2.0E+10	g/y

33 COIN, GOLD 1850 import = 5.3E+06 g/y (estimated from USTD (1852))

34 SERVICES embodied in imports 1850 =2.2E+08$/y (USTD, 1852)

The emergy-money ratio is that calculated in the 1860 Great Britain evaluation, converted from pounds sterling using the standard $4.9 per 1.0 £.

35 NET IMMIGRATION

1850 immigration = 3.7E+05 people/y (USCO, 1854)

The annual per capita emergy calculated in the 1860 Great Britain evaluation was multiplied by 16 years (an assumed value for the effective maturation, training, and education of an average 1860 immigrant) to obtain the emergy per person conversion used. The majority of 1860 immigrants were from Great Britain.

36 The transformity is a weighted average of the materials in this calculation.

PLANT LEAF & FIBER PRODUCTS

Cables & cordage	3.3E+08	g/y (USTD, 1852)
Cotton	4.2E+11	g/y (estimated from USTD (1852))
Hemp	2.2E+08	g/y(USTD, 1852)
Snuff	4.0E+07	g/y (USTD, 1852)
Manufactured tobacco	3.3E+09	g/y (USTD, 1852)
Tobacco leaf	1.3E+10	g/y (USTD, 1852)

1850 total export = 4.3E+11 g/y

1850 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1850 energy of export = 6.3E+15 J/y

GRAINS & BREADSTUFFS

Biscuit or ship bread	1.1E+10	g/y (estimated from USTD (1852))
Clover seed	0.0E+00	g/y (estimated from USTD (1852))
Flaxseed	1.2E+08	g/y (estimated from USTD (1852))
Indian corn	4.7E+10	g/y (estimated from USTD (1852))
Indian corn meal	1.8E+10	g/y (estimated from USTD (1852))
Rice	1.4E+10	g/y (estimated from USTD (1852))
Rye meal	4.0E+09	g/y (estimated from USTD (1852))
Rye, oats, & other small grain & pulse	3.3E+09	g/y (estimated from USTD (1852))
Wheat	1.4E+10	g/y (estimated from USTD (1852))
Wheat flour	2.0E+11	g/y (estimated from USTD (1852))

1850 total export = 3.1E+11 g/y

1850 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1850 energy of export = 4.8E+15 J/y

37 WOOD & WOOD PRODUCTS

Boards, plank, & scantling	5.9E+11	g/y (estimated from USTD (1852))
Hewn timber	1.2E+10	g/y (estimated from USTD (1852))
Shingles	4.0E+12	g/y (estimated from USTD (1852))
Staves and heading	7.5E+12	g/y (estimated from USTD (1852))

1850 total export = 1.2E+13 g/y

1850 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1850 energy in exports = 1.8E+17 J/y

38 COAL 1850 export = 1.0E+15 J/y (estimated from USTD (1862))

39 Cotton 4.2E+11 g/y (estimated from USTD (1852))

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1860 energy of export = 6.4E+15 J/y

40 The transformity is a weighted average of the materials in this calculation.

BUTTER & CHEESE

Cheese	4.7E+09	g/y (USTD, 1852)
Butter	1.8E+09	g/y (USTD, 1852)

1850 export = 6.5E+09 g/y

1850 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 3.3E+04 J/g (estimated from Odum (1969))

1850 energy of export = 1.6E+14 J/y

	OTHER ANIMAL PRODUCTS		
	Beef	8.2E+09	g/y (estimated from USTD (1852))
	Hides	3.9E+07	g/y (USTD, 1852)
	Hogs	1.5E+08	g/y (estimated from USTD (1852))
	Horned cattle	2.0E+08	g/y (estimated from USTD (1852))
	Horses	6.8E+08	g/y (estimated from USTD (1852))
	Lard	8.9E+09	g/y (USTD, 1852)
	Leather	1.0E+08	g/y (USTD, 1852)
	Leather boots & shoes	1.6E+08	g/y (estimated from USTD (1852))
	Mules	1.5E+09	g/y (estimated from USTD (1852))
	Pork	1.2E+11	g/y (estimated from USTD (1852))
	Sheep	2.0E+06	g/y (USTD, 1852)
	Soap	1.9E+09	g/y (USTD, 1852)
	Tallow	5.2E+09	g/y (USTD, 1852)
	Wax	1.9E+08	g/y (USTD, 1852)
	1850 total =	1.4E+11	g/y
	1850 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	0.30	g dry/g wet (estimated from Crampton & Harris (1969))
	energy/g =	2.1E+04	J/g (estimated from Odum (1969))
	1850 energy in exports =	8.9E+14	J/y
41	FISHERIES PRODUCTS		
	Fish, dried or smoked	6.2E+09	g/y (estimated from USTD (1852))
	pickled	2.0E+09	g/y (estimated from USTD (1852))
	1860 total =	8.1E+09	g/y
	1850 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	3.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
	energy/g =	2.1E+04	J/g (estimated from Odum (1969))
	1850 energy in exports =	1.7E+14	J/y
42	WHALE PRODUCTS:		
	Spermaceti candles	2.4E+08	g/y (USTD, 1852)
	Oil, spermaceti	2.9E+09	g/y (estimated from USTD (1852))
	whale and other fish	6.4E+09	g/y (estimated from USTD (1852))
	Whalebone	1.0E+09	g/y (USTD, 1852)
	1850 total =	1.1E+10	g/y
	1850 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	3.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
	energy/g =	2.1E+04	J/g (estimated from Odum (1969))
	1850 energy in exports =	6.6E+13	J/y
43	IRON EXPORT		
	Iron & manufactures of iron		
	bar	2.0E+08	g/y (USTD, 1852)
	nails	2.4E+09	g/y (USTD, 1852)
	pig	3.2E+08	g/y (USTD, 1852)
	manufactures of iron	2.5E+07	g/y (estimated from USTD (1852))
	total export =	2.9E+09	g/y
44	BULLION, Gold and silver — 1850 import =	2.6E+07	g/y (estimated from USTD (1852))
45	SERVICES — embodied in exports (1850) =	2.3E+08	$/y (USTD, 1852)
	The emergy-money ratio is that calculated for the U.S. in this evaluation.		

APPENDIX C
CALCULATIONS IN SUPPORT OF TABLE 3-9, EMERGY EVALUATION OF THE UNITED STATES IN 1860.

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term:

1 SOLAR ENERGY:
Effective continental shelf area, 1860 = 2.1E+11 m^2 (assumed as 30% of actual shelf area)
Farm area 1860= 1.7E+12 m^2 (estimated for improved and unimproved land area in farms in 1860 from USCO (1864)
Insolation = 4.6E+09 J/m^2-y
Albedo = 3.5E-01 (% given as decimal)
Energy = ((land area) + (shelf area))m^2 * (avg. insolation) J/m^2-y * (1-albedo)
Energy = 5.6E+21 J/y

2 WIND, KINETIC ENERGY
Wind energy = 4.9E+19 J/y (estimated from Odum et al. (1987a) for the land area in farms in 1860 (USCO, 1864))

3 RAIN, GEOPOTENTIAL ENERGY:
Area = 1.7E+16 cm^2
Rainfall = 110 cm
Average elevation = 4.6E+04 cm
Runoff rate = 0.80 %
Water density = 1.0 g/cm^3
Gravitational constant = 980 cm/s^2
Energy = (area) cm^2 * (runoff rate) * (rainfall) cm * (avg. elev.) cm * (water density) g/cm^3 * (gravitational constant.) cm/s^2 * 9.96E-08 J/erg
Energy = 6.8E+18 J/y

4 RAIN, CHEMICAL POTENTIAL ENERGY:
Farm area 1860 = 1.7E+12 m^2 (estimated from USCO (1864))
Continental Shelf = 2.1E+11 m^2 (estimated as
Rainfall = 1.1 m/y (estimated from USDC (1992)
Rain over shelf = 1.0E+00 m/y (estimated from USDC (1992)
Evapotranspiration rate = 5.0E-01 (percent given as decimal) (estimated)
Water density = 1.0E+03 kg/m^3
Gibbs free energy = 4.9E+03 J/kg
Energy over land = (area) m^2 * (Evapotranspiration) * (rainfall) m * (water density) kg/m^3 * (Gibbs free energy) J/kg
= 4.6E+18 J/y
Energy over shelf = (area) m^2 * (rainfall) m * (water density)kg/m^3 *(Gibbs free energy) J/kg
= 1.2E+18 J/y
Total energy = 5.8E+18 J/y

5 TIDAL ENERGY:
Effective continental shelf area, 1860 = 2.1E+15 cm^2 (assumed as 30% of actual shelf area)
Mean Tidal Range = 120 cm (estimated from Odum et al. (1987a))
Density = 1.0 g/cm^3
Number tides/y = 7.1E+02 (estimated from Odum et al. (1987a))
Absorption coefficient = 0.50 (assumed)
Gravitational constant = 980 m/s^2
Energy = (shelf area) cm^2 * (absorption coeff.) * (0.5) * (tides/y) * (mean tidal range)^2 cm^2 *(sea water density) g/cm^3 * (gravitational constant.) cm/s^2 *9.96E-08 J/erg
Energy = 5.3E+17 J/y

6 WAVE ENERGY:
Wave energy = 4.6E+18 J/y (estimated as 60% of Odum et al. (1987a))

7 EARTH CYCLE:
Land Area = 1.7E+12 m^2
Heat flow/ area = % area stable * heat + % area active * heat flow J/m^2/y
Heat flow/area = 1.1E+06 J/m^2-y
Energy = (Land area) m^2 (Heat flow per unit area) J/m^2-y
Energy = 1.8E+18 J/y

8 FORESTRY:
1859 harvest 1.7E+13 g/y (estimated from Steers (1948))
1859 energy of harvest = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.70 g-dry/g-wet (assumed)
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1859 energy of harvest = 2.0E+17 J/y

9 FUELWOOD USE: 1860 use = 2.8E+18 J/y (USDC, 1975)

10 HYDROPOWER:
1860 Hydropower = 2.1E+16 J/y (estimated from USCO (1874))

11 PLANT LEAF, FIBER, & OTHER PRODUCTS
1860 Hay = 1.7E+13 g/y (USCO, 1864)
1860 Flax = 2.1E+09 g/y (USCO, 1864)
1860 Hemp, dew rotted = 4.8E+10 g/y (USCO, 1864)
waterrotted = 3.6E+09 g/y (USCO, 1864)
other prepared = 1.6E+10 g/y (USCO, 1864)
1860 Tobacco = 2.0E+11 g/y (USCO, 1864)
1860 total production = 1.8E+13 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.85 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 2.5E+17 J/y

12 BREADSTUFFS & GRAINS
1860 Barley = 2.2E+11 g/y (estimated from USCO (1864))
1860 Buckwheat = 2.4E+11 g/y (estimated from USCO (1864))
1860 Clover seed = 1.3E+10 g/y (estimated from USCO (1864))
1860 Flaxseed = 7.7E+09 g/y (estimated from USCO (1864))
1860 Grass seeds = 1.2E+10 g/y (estimated from USCO (1864))
1860 Indian corn = 1.1E+13 g/y (estimated from USCO (1864))
1860 Oats = 2.3E+12 g/y (estimated from USCO (1864))
1860 Peas & beans = 2.0E+11 g/y (estimated from USCO (1864))
1860 Rice = 8.5E+10 g/y(USCO, 1864)
1860 Rye = 2.9E+11 g/y (estimated from USCO (1864))
1860 Wheat = 2.4E+12 g/y (estimated from USCO (1864))
1860 total production = 1.7E+13 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 2.6E+17 J/y

13 FRUIT & ROOT CROPS
1860 Hops = 5.0E+09 g/y (USCO, 1864)
1860 Irish potatoes = 1.5E+12 g/y (estimated from USCO (1864))
1860 Sweet potatoes = 5.7E+11 g/y (estimated from USCO (1864))
1860 total production = 2.1E+12 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 2.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 8.7E+15 J/y

14 GINNED COTTON
9.8E+11 g/y (estimated from USCO (1864))
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.4E+16 J/y

15 SUGAR & MOLASSES

1860 Cane molasses = 4.8E+10 g/y (estimated from USCO (1864))
1860 Cane sugar = 7.3E+11 g/y(USCO, 1864)
1860 Maple molasses = 5.1E+09 g/y (estimated from USCO (1864))
1860 Maple sugar = 1.8E+10 g/y(USCO, 1864)
1860 Sorghum molasses = 2.1E+10 g/y (estimated from USCO (1864))
1860 total production = 8.3E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.1E+16 J/y

16 SHELLFISH FISHERIES:

Energy of 1860 shellfish catch = (catch)g-live wt * (g-dry/g-live) * (J/g-dry)
1860 shellfish catch = 6.5E+09 g/y (estimated from USCO (1864))
g-dry/g-live = 2.6E-01 g-dry/g-live (estimated from NRC (1971))
J/g-dry = 2.1E+04 J/g-dry (estimated from Odum (1969))
Energy of catch = 3.5E+13 J/y

17 BUTTER & CHEESE

1860 Butter = 2.1E+11 g/y (USCO, 1864)
1860 Cheese = 4.7E+10 g/y(USCO, 1864)
1860 total production = 2.6E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 3.3E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 6.4E+15 J/y

18 FINFISH FISHERIES:

Energy of 1860 fish catch = (catch)g-live wt * (g-dry/g-live) * (J/g-dry)
1860 fish catch = 9.3E+09 g/y (estimated from USCO (1864))
g-dry/g-live = 2.6E-01 g-dry/g-live (estimated from NRC (1971))
J/g-dry = 2.1E+04 J/g-dry (estimated from Odum (1969))
Energy of catch = 5.1E+13 J/y

19 LIVESTOCK PRODUCTION:

1860 cattle prod.= 3.8E+11 g/y (estimated from USCO (1864))
1860 swine prod.= 5.0E+11 g/y (estimated from USCO (1864))
1860 sheep prod.= 8.2E+10 g/y (estimated from USCO (1864))
1860 horse prod.= 3.1E+11 g/y (estimated from USCO (1864))
1860 mule prod.= 5.8E+10 g/y (estimated from USCO (1864))
1860 total prod.= 1.3E+12 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 8.4E+15 J/y

20 WOOL

1860 Wool = 2.7E+10 g/y (USCO, 1864)
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 4.3E+14 J/y

21 SOIL LOSS

1860 improved farm land = 6.6E+07 ha (USCO, 1864)
Soil loss / improved ha = 1.5E+07 g/ha-y (estimated)
1860 total soil loss = 9.9E+14 g/y
Energy in soil loss = (Total loss) g/y * (% Organic matter) *(Energy/g organic matter) J/g * (dry weight/wet weight) g/g
% Organic matter = 3.25 % (estimated from Brady (1990))
Energy/g organic matter = 2.3E+04 J/g (estimated)
Dry weight/wet weight = 5.0E-01 g-dry/g-wet (estimated)
1860 energy in soil loss = 3.6E+17 J/y

22 COAL

1859-60 extraction
bituminous = 1.7E+17 J/y (from USCO (1864))
anthracite = 2.2E+17 J/y (from USCO (1864))
total = 3.9E+17 J/y

23 CRUDE PETROLEUM:

1860 extraction = 5.0E+05 bbl/y (Rothwell, 1892)
6.1E+09 J/bbl (Shonka, 1979)
Energy (J/y) = (bbl/y) * (J/bbl)
Energy = 3.1E+15 J/y

24 IRON ORE; 1860 extraction = 2.4E+12 g/y (from Rothwell (1892))
The transformity used is the average of those for iron pig and iron products (this study).

25 COPPER ORE 1860 extraction = 1.5E+10 g/y (from USCO (1864))
NICKEL ORE 1860 extraction = 2.4E+09 g/y (from USCO (1864))
LEAD ORE: 1860 extraction = 1.2E+10 g/y (from USCO (1864))
Transformity is the lead pig transformity calculated in this study.
ZINC ORE: 1860 extraction = 1.2E+10 g/y (from USCO (1864))
MERCURY (Quicksilver) 1860 extraction = 1.0E+08 g/y (from Rothwell (1892))

26 SILVER:

1860 extraction 3.6E+06 g/y (from Rothwell (1892))
The transformity used for silver is from Sundberg et al. (1994a) for exported, 17th-century, Swedish silver coins.
GOLD: 1860 extraction 6.9E+07 g/y (from Rothwell (1892))
The transformity used for silver and gold is a weighted average of the two.

27 The transformity is a weighted average of the plant products in this calculation.
FRUITS, GREEN, RIPE OR DRIED
currants 2.7E+09 g/y (USTD, 1860)
dates 1.4E+09 g/y (USTD, 1860)
figs 3.4E+09 g/y (USTD, 1860)
plums 4.2E+06 g/y (USTD, 1860)
prunes 2.3E+08 g/y (USTD, 1860)
raisins 1.1E+10 g/y (USTD, 1860)
Total 1860 import = 2.0E+10 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 5.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 1.7E+14 J/y
PLANT LEAF, BARK, & FIBER & INSECT PRODUCTS
Arrowroot 8.8E+07 g/y (USTD, 1860)
Bristles 2.8E+08 g/y (USTD, 1860)
Camphor, crude 2.2E+07 g/y(USTD, 1860)
Bark, quilla 1.0E+06 g/y (USTD, 1860)
all other kinds not otherwise detailed 1.2E+07 g/y (USTD, 1860)
Cochineal 1.3E+08 g/y (USTD, 1860)
Cocoa 1.4E+09 g/y (USTD, 1860)
Gums 2.8E+09 g/y (USTD, 1860)
Indigo 7.7E+08 g/y (USTD, 1860)
Licorice, paste 2.4E+09 g/y (USTD, 1860)
Licorice, root 1.2E+09 g/y (USTD, 1860)
Nuts 1.3E+09 g/y (USTD, 1860)
Spices
cassia 7.7E+08 g/y (USTD, 1860)
cinnamon 1.9E+07 g/y (USTD, 1860)
cloves 2.4E+08 g/y (USTD, 1860)
ginger 5.0E+08 g/y (USTD, 1860)
mace 2.1E+07 g/y (USTD, 1860)
nutmegs 2.3E+08 g/y (USTD, 1860)
pepper, red 3.8E+09 g/y (USTD, 1860)
black 4.2E+07 g/y (USTD, 1860)
pimento 7.3E+08 g/y (USTD, 1860)

Cordage, tarred and cables 5.6E+08 g/y(USTD, 1860)
un tarred 2.1E+08 g/y(USTD, 1860)
Tea 1.2E+10 g/y (USTD, 1860)
Coffee 8.2E+10 g/y (USTD, 1860)
Total 1860 import = 1.1E+11 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 1.6E+15 J/y

SUGAR
brown 3.0E+11 g/y (USTD, 1860)
candy 1.6E+07 g/y (USTD, 1860)
loafed & other refined 3.5E+08 g/y (USTD, 1860)
syrup of sugar cane 3.9E+07 g/y (USTD, 1860)
white, clayed, or powdered 4.7E+08
Molasses 9.8E+10
Total 1860 import = 4.0E+11 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 6.1E+15 J/y
Total energy of import =

28 COAL 1860 coal import = 6.7E+15 J/y (estimated from USTD (1860))

29 FISH, DRIED, SMOKED OR PICKLED
dried or smoked 3.0E+09 g/y (estimated from USTD, 1860)
herring 5.0E+08 g/y (estimated from USTD, 1860)
mackerel 5.3E+06 g/y (estimated from USTD, 1860)
salmon 3.6E+05 g/y (estimated from USTD, 1860)
all other 6.9E+07 g/y (USTD, 1860)
1860 total = 3.6E+09 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 2.2E+13 J/y

30 WHALE PRODUCTS OF OFFSHORE & FOREIGN FISHERIES
sperm oil 7.0E+09 g/y (estimated from USCO (1864))
whale oil 1.3E+10 g/y (estimated from USCO (1864))
whale bone 6.1E+08 g/y (estimated from USCO (1864))
Total import & landing = 2.1E+10 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 1.3E+14 J/y

31 PLANT DERIVED ASH & SODA
Barilla 3.7E+08 g/y (USTD, 1860)
Soda, ash 3.8E+10 g/y (USTD, 1860)
Soda, carbonate 7.7E+09 g/y (USTD, 1860)
Soda, sal. 5.1E+09 g/y (USTD, 1860)
1860 total import = 5.1E+10 g/y

32 IRON, STEEL, & MANUFACTURES OF

bar iron	9.6E+10	g/y (USTD, 1860)
hoop iron	1.1E+09	g/y (USTD, 1860)
nails, spikes, & tacks	6.1E+08	g/y (USTD, 1860)
old & scrap	8.3E+09	g/y (USTD, 1860)
pig	6.5E+10	g/y (USTD, 1860)
rod	3.8E+10	g/y (USTD, 1860)
sheet iron	1.4E+10	g/y (USTD, 1860)
steel	1.8E+10	g/y (USTD, 1860)
wire, cap & bonnet	1.1E+08	g/y (USTD, 1860)
cables, chain	2.3E+09	g/y (USTD, 1860)
anchors & anchor parts	1.3E+08	g/y (USTD, 1860)
anvils & anvil parts	3.4E+08	g/y (USTD, 1860)
muskets & rifles	1.1E+07	g/y (estimated from USTD, 1860)
railroad	1.1E+11	g/y (USTD, 1860)
total import =	3.6E+11	g/y

33 The transformity is a weighted average of the materials in this calculation.

CHALK import =	9.2E+09	g/y (USTD, 1860)
BRIMSTONE, crude (Sulfur) =	1.6E+10	g/y(USTD, 1860)

LEAD & MANUFACTURES OF

bar, pig, sheet, & old	1.9E+10	g/y (USTD, 1860)
pipes	2.9E+07	g/y (USTD, 1860)
Total import =	1.9E+10	g/y

34 COIN, SILVER import = 9.0E+07 g/y (USTD, 1860)

35 COIN, GOLD import = 2.1E+06 g/y (USTD, 1860)

36 ADDITIONAL SERVICES IN IMPORTS, not accounted for above

embodied in imports (1860) = 3.6E+08 $/y (USTD, 1860)

services accounted for in transformities of products in terms above

= 1.0E+07 $/y

services embodied in imports that are not accounted for above

= 3.4E+08 $/y

The emergy-money ratio is that calculated in the 1860 Great Britain evaluation, converted from pounds sterling using the standard $4.9 per 1.0 £.

37 NET IMMIGRATION

1860 immigration = 1.5E+05 people/y (USDC ,1975)

The annual per capita emergy calculated in the 1860 Great Britain evaluation was multiplied by 16 years (an assumed value for the effective maturation, training, and education of an average 1860 immigrant) to obtain the emergy per person conversion used. The majority of 1860 immigrants were from Great Britain.

38 The transformity is a weighted average of the materials in this calculation.

PLANT LEAF & FIBER PRODUCTS

Cables & cordage	1.3E+09	g/y (USTD, 1860)
Hemp	1.7E+08	g/y (USTD, 1860)
Snuff	1.8E+07	g/y (USTD, 1860)
Manufactured tobacco	8.0E+09	g/y (USTD, 1860)
Tobacco leaf	2.6E+10	g/y (USTD, 1860)
Coffee (foreign product)	9.1E+09	g/y (USTD, 1860)
Tea (foreign product)	2.4E+09	g/y (USTD, 1860)
Cocoa (foreign product)	9.1E+08	g/y (USTD, 1860)
Dried fruit (foreign product)	1.2E+09	g/y (USTD, 1860)
1860 total export =	4.9E+10	g/y

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1860 energy of export = 7.0E+14 J/y

GRAINS & BREADSTUFFS

Biscuit or ship bread	1.3E+10	g/y (estimated from USTD (1860))
Clover seed	1.6E+09	g/y (estimated from USTD (1860))
Flaxseed	3.7E+07	g/y (estimated from USTD (1860))
Indian corn	4.5E+10	g/y (from USTD (1860))
Indian corn meal	2.1E+10	g/y (from USTD (1860))
Rice	1.8E+10	g/y (from USTD (1860))
Rye meal	1.0E+09	g/y (from USTD (1860))
Wheat	5.7E+10	g/y (from USTD (1860))
Wheat flour	2.4E+11	g/y (from USTD (1860))
1860 total export =	3.9E+11	g/y

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	9.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	1.7E+04	J/g (estimated from Odum (1969))
1860 energy of export =	6.0E+15	J/y

39 WOOD & WOOD PRODUCTS

Boards, plank, & scantling	1.0E+12	g/y (estimated from USTD (1860))
Hewn timber	2.9E+10	g/y (USTD, 1860)
Lumber, other	8.9E+10	g/y (USTD, 1860)
Shingles	4.7E+12	g/y (estimated from USTD (1860))
Staves and heading	1.7E+10	g/y (estimated from USTD (1860))
1860 total export =	5.9E+12	g/y

1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	9.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	1.7E+04	J/g (estimated from Odum (1969))
1860 energy in exports =	9.0E+16	J/y

40 COAL 1860 export = 5.2E+15 J/y (estimated from USTD (1860))

41 COTTON

1860 export =	8.0E+11	g/y (USTD, 1860)

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	8.5E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	1.7E+04	J/g (estimated from Odum (1969))
1860 energy of export =	1.2E+16	J/y

42 The transformity is a weighted average of the materials in this calculation.

BUTTER & CHEESE

Cheese	7.0E+09	g/y (USTD, 1860)
Butter	3.5E+09	g/y (USTD, 1860)
1860 export =	1.1E+10	g/y

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	7.5E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	3.3E+04	J/g (estimated from Odum (1969))
1860 energy of export =	2.6E+14	J/y

OTHER ANIMAL PRODUCTS

Adamantine & other candles	2.2E+09	g/y (USTD, 1860)
Beef	1.7E+10	g/y (estimated from USTD (1860))
Hams & bacon	1.2E+10	g/y (USTD, 1860)
Hogs	7.3E+09	g/y (estimated from USTD (1860))
Horned cattle	4.1E+09	g/y (estimated from USTD (1860))
Horses	8.2E+08	g/y (estimated from USTD (1860))
Lard	1.8E+10	g/y (USTD, 1860)
Lard oil	1.9E+08	g/y (estimated from USTD (1860))
Leather	1.3E+09	g/y (USTD, 1860)
Leather boots & shoes	3.9E+08	g/y (estimated from USTD (1860))
Mules	7.2E+08	g/y (estimated from USTD (1860))
Pork	1.9E+10	g/y (estimated from USTD (1860))
Soap	3.1E+09	g/y (USTD, 1860)
Tallow	6.9E+10	g/y (USTD, 1860)
Wax	1.6E+08	g/y (USTD, 1860)
Wool	5.4E+08	g/y (USTD, 1860)
1860 total =	9.3E+10	g/y

1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	3.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1860 energy in exports =	5.8E+14	J/y

43 FISHERIES PRODUCTS
Fish, dried or smoked 1.1E+10 g/y (estimated from USTD (1860))
pickled 4.1E+09 g/y (estimated from USTD (1860))
1860 total = 1.5E+10 g/y
1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in exports = 3.1E+14 J/y

44 WHALE PRODUCTS:
Spermaceti candles 7.2E+07 g/y (USTD, 1860)
Oil, spermaceti 4.4E+09 g/y (estimated from USTD (1860))
whale and other fish 3.3E+09 g/y (estimated from USTD (1860))
Whalebone 4.8E+08 g/y (USTD, 1860)
1860 total = 8.2E+09 g/y
1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in exports = 5.1E+13 J/y

45 IRON EXPORT
Iron & manufactures of iron
bar 4.8E+08 g/y (USTD, 1860)
castings 3.1E+09 g/y (USTD, 1860)
nails 2.3E+09 g/y (USTD, 1860)
pig 4.1E+08 g/y (USTD, 1860)
manufactures of iron 2.0E+09 g/y (estimated from USTD (1860))
total export = 8.3E+09 g/y

46 COIN & BULLION Gold and silver = 4.1E+07 g/y (estimated from USTD (1860))

47 ADDITIONAL SERVICES IN EXPORTS, not accounted for above
embodied in exports (1860) = 4.0E+08 $/y (USTD, 1860)
services accounted for in transformities of products in terms above
= 2.9E+08 $/y
services embodied in imports that are not accounted for above
= 1.1E+08 $/y
The emergy-money ratio is that calculated for the U.S. in this evaluation.

APPENDIX D

CALCULATIONS IN SUPPORT OF TABLE 3-12, EMERGY EVALUATION OF THE UNITED STATES IN 1870.

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term:

1 SOLAR ENERGY:
Effective continental shelf area, 1870 = 2.1E+15 m^2 (assumed as 30% of actual shelf area)
Farm area 1870 = 1.7E+12 m^2 (from USCO (1874))
Insolation = 4.6E+09 J/m^2/y (estimated from Kung et al. (1964))
Albedo = 0.53 (estimated from Kung et al. (1964))
Energy = ((land area) + (shelf area))m^2 * (avg. insolation) J/m^2-y * (1-albedo)
Energy = 5.6E+21 J/y

2 WIND, KINETIC ENERGY
Wind energy = 6.2E+18 J/y (estimated from Odum et al. (1987a) for the land area in farms in 1870 (USCO, 1874))

3 RAIN, GEOPOTENTIAL ENERGY:
Farm area 1870 = 1.7E+12 cm^2 (from USCO (1874))
Rainfall = 1.1E+02 cm (estimated from NOAA (1977))
Average elevation = 4.6E+04 cm (estimated)
Runoff rate = 8.0E-01 % (estimated)
Water density = 1.0E+00 g/cm^3
Gravitational constant = 9.8E+02 cm/s^2
Energy = (area) cm^2 * (runoff rate) * (rainfall) cm * (avg. elevation) cm * (water density) g/cm^3 * (gravitational constant) cm/s^2 * 9.96E-08 J/erg
Energy = 6.8E+18 J/y

4 RAIN, CHEMICAL POTENTIAL ENERGY:
Farm area 1870 = 1.7E+12 m^2 (estimated from USCO (1874))
Effective continental shelf area, 1870 = 2.1E+11 m^2 (assumed as 30% of actual shelf area)
Rainfall 7= 1.1E+00 m/y (estimated from NOAA (1977))
Rain over shelf = 1.0E+00 m/y (estimated from NOAA (1977))
Evapotranspiration rate = 5.0E-01 (percent given as decimal) (estimated)
Water density = 1.0E+03 kg/m^3
Gibbs free energy = 4.9E+03 J/kg
Energy over land = (area) m^2 * (Evapotranspiration) * (rainfall) m * (water density) kg/m^3 * (Gibbs free energy J/kg
Energy = 4.6E+18 J/y
Energy over shelf = (area) m^2 * (rainfall) m * (water density) kg/m^2 * (Gibbs free energy) J/kg
Energy = 1.2E+18 J/y
Total energy = 5.8E+18 J/y

5 TIDAL ENERGY:
Effective continental shelf area, 1870 = 2.1E+15 cm^2 (assumed as 30% of actual shelf area)
Mean Tidal Range = 1.2E+02 cm (estimated from USCGS (1956))
Density = 1.0 g/cm^2
Number tides/y = 7.1E+02 (estimated from Odum et al. (1987a))
Absorption coefficient = 0.50 (assumed)
Gravitational constant = 980 cm/s^2
Energy = (shelf area) cm^2 * (absorption coeff.) * (0.5) * (tides/y) * (mean tidal range)^2 (cm)^2 *(sea water density) g/cm^3 * (gravitational constant) cm/s^3 * 9.96E-08 J/erg
Energy = 5.3E+17 J/y

6 WAVES:
Energy = 4.6E+18 J/y (estimated as 60% of Odum et al. (1987a))

7 EARTH CYCLE:
Farm land area 1870 = 1.7E+12 m^2 (from USCO (1870))
Heat flow / area = % area stable * heat + % area active * heat flow $J/m^2/y$
Heat flow/area = 1.1E+06 J/m^2-y (estimated from Odum et al. (1987a))
Energy = (Land area) m^2 (Heat flow per unit area) J/m^2-y
Energy = 1.8E+18 J/y

8 FORESTRY:
1869 harvest 2.6E+13 g/y (estimated from Steers (1948))
1869 energy of harvest = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.70 g-dry/g-wet (assumed)
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1869 energy of harvest = 3.1E+17 J/y

9 FUELWOOD USE: 1870 use = 3.2E+18 J/y (USDC, 1975)

10 HYDROPOWER:
1870 Hydropower = 2.7E+16 J/y (estimated from USCO (1874))

11 PLANT LEAF, FIBER, & PRODUCTS
1870 Hay = 2.5E+13 g/y (USCO, 1874)
1870 Flax = 1.2E+10 g/y (USCO, 1874)
1870 Hemp, dew rotted = 1.2E+10 g/y (USCO, 1874)
1870 Tobacco = 1.2E+11 g/y (USCO, 1874)
1870 total production = 2.5E+13 g/y
1870 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of prod. = 3.6E+17 J/y

12 BREADSTUFFS & GRAINS
1870 Barley = 4.0E+11 g/y (estimated from USCO (1874))
1870 Buckwheat = 1.3E+11 g/y (estimated from USCO (1874))
1870 Clover seed = 8.7E+09 g/y (estimated from USCO (1874))
1870 Flaxseed = 2.4E+10 g/y (estimated from USCO (1874))
1870 Grass seeds = 7.9E+09 g/y (estimated from USCO (1874))
1870 Indian corn = 1.0E+13 g/y (estimated from USCO (1874))
1870 Oats = 3.8E+12 g/y (estimated from USCO (1874))
1870 Peas & beans = 7.8E+10 g/y (estimated from USCO (1874))
1870 Rice = 3.3E+10 g/y (USCO, 1874)
1870 Rye = 2.3E+11 g/y (estimated from USCO (1874))
1870 Wheat = 3.9E+12 g/y (estimated from USCO (1874))
1870 total production = 1.9E+13 g/y
1870 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of prod. = 2.9E+17 J/y

13 FRUIT & ROOT CROPS
1870 Hops = 1.2E+10 g/y (USCO, 1874)
1870 Irish potatoes = 2.0E+12 g/y (estimated from USCO (1874))
1870 Sweet potatoes = 3.0E+11 g/y (estimated from USCO (1874))
1870 total production = 2.3E+12 g/y
1870 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 2.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of prod. = 9.4E+15 J/y

14 GINNED COTTON
1870 production = 5.5E+11 g/y (estimated from USCO (1874))
1870 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of production = 7.9E+15 J/y

15 SUGAR & MOLASSES

1870 Cane molasses = 3.3E+10 g/y (estimated from USCO (1874))
1870 Cane sugar = 2.8E+10 g/y (USCO, 1874)
1870 Maple molasses = 2.9E+09 g/y (estimated from USCO (1874))
1870 Maple sugar = 1.3E+10 g/y (USCO, 1874)
1870 Sorghum molasses = 8.0E+10 g/y (estimated from USCO (1874))
1870 total production = 1.6E+11 g/y
1870 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet(estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of prod. = 2.0E+15 J/y

16 SHELLFISH FISHERIES:

1870 shellfish catch = 6.5E+09 g/y (estimated from USCO (1874))
g-dry/g-live = 2.6E-01 g-dry/g-live (estimated from NRC (1971))
J/g-dry = 2.1E+04 J/g-dry (estimated from Odum (1969))
Energy of 1870 shellfish catch = (catch)g-live wt * (g-dry/g-live) * (J/g-dry)
Energy of catch = 3.5E+13 J/y

17 BUTTER & CHEESE

1870 Butter = 2.3E+11 g/y (USCO, 1874)
1870 Cheese = 2.4E+10 g/y(USCO, 1874)
1870 total production = 2.6E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 3.3E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 6.5E+15 J/y

18 FINFISH FISHERIES:

No 1870 Census data.

19 LIVESTOCK PRODUCTION:

1870 cattle prod.= 3.6E+11 g/y (estimated from USCO (1874))
1870 swine prod.= 3.8E+11 g/y (estimated from USCO (1874))
1870 sheep prod.= 1.0E+11 g/y (estimated from USCO (1874))
1870 horse prod.= 3.6E+11 g/y (estimated from USCO (1874))
1870 mule prod.= 5.6E+10 g/y (estimated from USCO (1874))
1870 total prod.= 1.3E+12 g/y
1870 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1870 energy of prod. = 7.8E+15 J/y

20 WOOL

1870 Wool = 4.5E+10 g/y (USCO, 1874)
1870 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1870 energy of prod. = 7.2E+14 J/y

21 SOIL LOSS

1870 improved farm land = 7.7E+07 ha (USCO, 1864)
Soil loss / improved ha = 1.5E+07 g/ha-y (estimated)
1870 total soil loss = 1.2E+15 g/y
Energy in soil loss = (Total loss) g/y * (% Organic matter) *(Energy/g organic matter) J/g * (dry weight/wet weight) g/g
% Organic matter = 3.3E+00 % (estimated from Brady (1990))
Energy/g organic matter = 2.3E+04 J/g (assumed)
Dry weight/wet weight = 5.0E-01 g-dry/g-wet (estimated)
1870 energy in soil loss = 4.2E+17 J/y

22 COAL

1870 extraction
bituminous = 5.7E+17 J/y (U.S. Census Office, 1874)
anthracite = 5.4E+17 J/y (U.S. Census Office, 1874)
total = 1.1E+18 J/y

23 CRUDE PETROLEUM: 1870 extraction = 3.2E+16 J/y (Rothwell, 1892)

24 IRON ORE 1870 extraction = 5.4E+12 g/y (Rothwell, 1892)

25 The transformity is a weighted average of the materials in this calculation.
COPPER ORE 1870 extraction = 1.3E+10 g/y (USCO, 1874)
LEADORE 1870 extraction = 1.8E+10 g/y(USCO, 1874)
ZINC ORE 1870 extraction = 5.5E+09 g/y (USCO, 1874)
MERCURY (Quicksilver) 1870 extraction = 1.0E+09 g/y (Rothwell, 1892)

26 SILVER: 1870 extraction 3.8E+08 g/y (from Rothwell, 1892)

27 GOLD: 1870 extraction 7.5E+07 g/y (from Rothwell, 1892)

28 The transformity is a weighted average of the materials in this calculation.
PLANT LEAF, BARK, & FIBER & INSECT PRODUCTS :
Cochineal 5.7E+08
Cocoa 1.7E+09
Gums 4.0E+09
Indigo 5.8E+08
Madder, root 4.4E+09
Spices, cassia 6.9E+09
Tea 2.2E+10
Coffee 1.1E+11
Total 1870 import = 1.5E+11 g/y
1870 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of import = 2.1E+15 J/y
SUGAR
brown 5.3E+11
candy 2.5E+07
loafed & other refined 6.9E+07
syrup of sugar cane 1.6E+10
Molasses 1.8E+11
Total 1870 import = 7.2E+11 g/y
1870 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.90 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 1.1E+16 J/y

29 COAL 1860 coal import = 1.2E+16 J/y (estimated from USTD (1872))

30 FISH, DRIED, SMOKED OR PICKLED
herring 7.1E+09
mackerel 7.2E+09
1870 total = 1.4E+10 g/y
1870 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1870 energy in imports = 8.9E+13 J/y

31 PLANT DERIVED ASH & SODA
Soda, carbonate 5.8E+09
Soda, sal. 6.6E+10
Soda, unspecified 2.2E+10
1870 total import = 9.4E+10 g/y

32 IRON, STEEL, & MANUFACTURES OF
bar iron 7.2E+10
hoop iron 6.1E+09
old & scrap 6.7E+07
pig 1.6E+11
sheet iron 9.5E+09
anchors & anchor parts 5.0E+09
railroad 2.8E+11
total import = 5.3E+11 g/y

33 The transformity is a weighted average of the materials in this calculation.
CHLORIDE OF LIME 1870 import = 1.0E+10 g/y
BRIMSTONE, CRUDE (Sulfur) import = 2.8E+10 g/y (USTD, 1872)
LEAD & manufactures of import = 4.0E+10 g/y

34 SILVER, COIN & BULLION import = 3.6E+08 g/y (estimated from USDC (1975) and USTD (1879))

35 GOLD, COIN & BULLION import = 2.6E+07 g/y (estimated from USDC (1975) and USTD (1879))

36 SERVICES embodied in imports (1870) = 2.9E+08 $/y (USTD, 1872)
The emergy-money ratio is that calculated in the 1860 Great Britain evaluation, converted from pounds sterling using the standard $4.9 per 1.0 £.

37 NET IMMIGRATION
1870 immigration = 3.9E+05 people/y (USCO, 1874)
The annual per capita emergy calculated in the 1860 Great Britain evaluation was multiplied by 16 years (an assumed value for the effective maturation, training, and education of an average 1860 immigrant) to obtain the emergy per person conversion used. The majority of 1860 immigrants were from Great Britain.

38 The transformity is a weighted average of the materials in this calculation.
PLANT LEAF & FIBER PRODUCTS
Snuff 9.2E+06 g/y (USTD, 1872)
Tobacco leaf 8.4E+10 g/y (USTD, 1872)
1870 total export = 8.4E+10 g/y
1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of export = 1.2E+15 J/y
GRAINS & BREADSTUFFS
Biscuit or ship bread 9.2E+11 g/y (estimated from USTD (1872))
Flaxseed 4.8E+05 g/y (estimated from USTD (1872))
Indian corn 1.9E+10 g/y (estimated from USTD (1872))
Indian corn meal 1.7E+10 g/y (estimated from USTD (1872))
Rice 9.7E+08 g/y (estimated from USTD (1872))
Rye meal 6.3E+08 g/y (estimated from USTD (1872))
Rye, oats, & other small grain & pulse 7.3E+09 g/y (estimated from USTD (1872))
Wheat 5.0E+11 g/y (estimated from USTD (1872))
Wheat flour 3.1E+11 g/y (estimated from USTD (1872))
1860 total export = 1.8E+12 g/y
1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of export = 2.7E+16 J/y

39 WOOD & WOOD PRODUCTS
Boards, plank, & scantling 8.3E+11 g/y (estimated from USTD (1872))
Hewn timber 1.4E+11 g/y (USTD, 1872)
Shingles 3.3E+12 g/y (estimated from USTD (1872))
1870 total export = 4.2E+12 g/y
1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.90 g dry/g wet g dry/g wet (assumed)
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy in exports = 6.5E+16 J/y

40 COTTON
1870 export = 4.3E+11 g/y (estimated from USTD (1872))
1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 0.90 g dry/g wet g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1870 energy of export = 6.7E+15 J/y

41 COAL 1860 coal export = 6.3E+15 J/y (estimated from USTD (1872))

42 The transformity is a weighted average of the materials in this calculation.
BUTTER & CHEESE

Cheese	2.6E+10	g/y (USTD, 1872)
Butter	9.2E+08	g/y (USTD, 1872)
1870 export =	2.7E+10	g/y

1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	0.75	g dry/g wet g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	3.3E+04	J/g (estimated from Odum (1969))
1870 energy of export =	6.8E+14	J/y

OTHER ANIMAL PRODUCTS

Adamantine & other candles	1.0E+09	g/y (USTD, 1862)
Beef	1.2E+10	g/y (estimated from USTD (1862))
Hams & bacon	1.8E+10	g/y (USTD, 1862)
Lard	1.6E+10	g/y (USTD, 1862)
Lard oil	2.9E+08	g/y (estimated from USTD (1862))
Pork	1.1E+10	g/y (estimated from USTD (1862))
Soap	3.5E+09	g/y (USTD, 1862)
Tallow	1.7E+10	g/y (USTD, 1862)
Wool	6.9E+07	g/y (USTD, 1862)
1870 total =	7.9E+10	g/y

1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	0.30	g dry/g wet g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1870 energy in exports =	5.0E+14	J/y

43 FISHERIES PRODUCTS

Fish, dried or smoked	4.6E+09	g/y (estimated from USTD (1872))
pickled	2.8E+09	g/y (estimated from USTD (1872))
1870 total =	7.4E+09	g/y

1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	0.30	g dry/g wet g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1870 energy in exports =	1.5E+14	J/y

44 WHALE PRODUCTS:

Spermaceti	3.7E+07	g/y (USTD, 1872)
Oil, spermaceti	1.6E+09	g/y (estimated from USTD (1872))
whale and other fish	9.9E+08	g/y (estimated from USTD (1872))
Whalebone	1.8E+08	g/y (USTD, 1872)
1870 total =	2.8E+09	g/y

1870 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	0.30	g dry/g wet g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1870 energy in exports =	1.8E+13	J/y

45 IRON EXPORT

Iron & manufactures of iron		
bar	2.3E+08	g/y (USTD, 1872)
other	7.1E+07	g/y (USTD, 1872)
nails	2.1E+09	g/y (USTD, 1872)
pig	1.4E+09	g/y (USTD, 1872)
total export =	3.8E+09	g/y

46 SILVER BULLION & COIN export = 6.5E+08 g/y (estimated from USDC (1975) and USTD (1879))

47 GOLD BULLION & COIN export = 3.7E+07 g/y (estimated from USDC (1975) and USTD (1879))

48 SERVICES embodied in exports (1870) = 5.0E+08 $/y (USTD, 1872)
The emergy money ratio is that calculated for the U.S. in this evaluation.

APPENDIX E

CALCULATIONS IN SUPPORT OF TABLE 3-15, EMERGY EVALUATION OF GREAT BRITAIN IN 1860.

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term:

1 SOLAR ENERGY:

Effective continental shelf area = 1.9E+11 m^2 (estimated as 30% of shelf area)
Land area= 3.13E+11 m^2 (UKCSO, 1992)
Insolation= 3.2E+09 J/m^2-y (estimated from Lindsberg et al. (1965))
Albedo = 0.35 (% given as decimal, estimated)
Energy = ((land area) + (shelf area))m^2 * (avg. insolation) J/m^2-y * (1-albedo)
Energy= 1.1E+21 J/y

2 WIND, KINETIC ENERGY

1860 absorption of wind energy below 300 ft. = 2.94E+18 J/y (S. Tennebaum, Unpublished Data. University of Florida Center for Wetlands and Water Resources)

3 RAIN, GEOPOTENTIAL ENERGY:

Area = 3.1E+15 m^2 (estimated)
Rainfall = 1.1E+02 m^2 (UKCSO, 1992)
Average elev. = 7.5E+03 cm (estimated)
Runoff rate = 8.0E-01 %
Water density = 1.0E+00 g/cm^3
Gravitational constant = 9.8E+02 cm/s^2
Energy = (area) cm^2 * (runoff rate) * (rainfall) cm * (avg. elev.) cm * (water density) g/cm^3 * (gravitational constant) cm/s^2 * 9.96E-08 J/erg
Energy = 2.0E+17 J/y

4 RAIN, CHEMICAL POTENTIAL ENERGY:

Area = 3.1E+11 m^2 (UKCSO(1992))
Effective continental shelf area = 1.9E+11 m^2 (estimated as 30% of shelf area)
Rainfall = 1.1 m/y (estimated from UKCSO (1992))
Rain over shelf = 1.0 m/y (estimated from UKCSO (1992))
Evapotranspiration rate = 0.50 (percent given as decimal) (estimated)
Water density = 1000 kg/m^3
Gibbs free energy = 4900 J/kg
Energy over land = (area) m^2 * (Evapotranspiration) * (rainfall) m * (water density) kg/m^3 * (Gibbs free energy) J/kg
= 8.8E+17 J/y
Energy over shelf= (area) m^2 * (rainfall) m * (water density)kg/m^3 *(Gibbs free energy)J/kg
= 1.1E+18 J/y
Total energy = 1.9E+18 J/y

5 TIDAL ENERGY:

Continental Shelf= 1.9E+15 cm^2 (estimated)
Mean Tidal Range = 3.8E+02 cm (estimated from Gierloff-Emden (1986))
Density = 1.0 g/cm^3
Number tides/y = 730 (estimated from Gierloff-Emden (1986))
Absorption coefficient = 0.10 (assumed)
Gravitational constant = 980 cm/s^2
Energy = (shelf area) cm^2 * (absorption coeff.) * (0.5) * (tides/y) * (mean tidal range)^2 (cm)^2 *(sea water density) g/cm^3 * (gravitational constant.) cm/s^2 *9.96E-08 J/erg
Energy = 9.6E+17 J/y

6 WAVE ENERGY:

1860 absorption of coastal wave energy = 2.94E+18 J/y (estimated as 10% of the value given by S. Tennebaum (Unpublished Data, University of Florida Center for Wetlands and Water Resources) for the U.K. in 1980)

7 EARTH CYCLE ENERGY:

Land Area = 3.1E+11 m^2

Heat flow/area = 1.0E+06 J/m^2-y (estimated from Sclater et al. (1980))

Energy = (Land area) m^2 (Heat flow per unit area) J/m^2-y

Energy = 3.1E+17 J/y

8 SOIL LOSS

1860 improved farm land = 1.6E+06 ha (estimated from GBCSO (1872))

Soil loss / improved ha = 1.5E+07 g/ha-y (estimated)

1860 total soil loss = 2.4E+13 g/y

% Organic matter = 3.3E+00 % (estimated from Brady (1990))

Energy/g organic matter = 2.3E+04 J/g (estimated)

Dry weight/wet weight = 5.0E-01 g-dry/g-wet (estimated)

Energy in soil loss = (Total loss) g/y * (% Organic matter) *(Energy/g organic matter) J/g * (dry weight/wet weight) g/g

1860 energy in soil loss = 8.7E+15 J/y

9 COAL 1860 extraction = 2.2E+18 J/y (GBCSO, 1872)

10 IRON, Pig 1860 extraction = 3.9E+12 g/y (GBCSO, 1872)

11 COPPER ORE 1860 extraction = 2.4E+11 g/y (Mitchell, 1962)

12 TIN ORE 1860 extraction = 1.1E+10 g/y (Mitchell, 1962)

13 LEAD ORE 1860 extraction = 9.0E+10 g/y (Mitchell, 1962)

14 ZINC ORE 1860 extraction = 4.4E+09 g/y (Mitchell, 1962)

15 The transformity is a weighted average of the materials in this calculation.

FRUITS, GREEN, RIPE OR DRIED

currants 3.4E+10 g/y (GBCSO, 1872)

oranges & lemons 3.1E+07 g/y (estimated from GBCSO (1872))

raisins 1.1E+10 g/y (GBCSO, 1872)

Total 1860 import = 4.5E+10 g/y

1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 5.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1860 energy of import = 3.9E+14 J/y

PLANT LEAF, BARK, & FIBER & INSECT PRODUCTS

Bristles 1.1E+09 g/y (GBCSO, 1872)

Dyewood 4.2E+10 g/y(GBCSO, 1872)

Cochineal 1.1E+09 g/y (GBCSO, 1872)

Cocoa 4.1E+09 g/y (GBCSO, 1872)

Grains

barley 3.4E+11 g/y (GBCSO, 1872)

oats 2.9E+09 g/y (GBCSO, 1872)

other 3.8E+07 g/y (GBCSO, 1872)

rice 6.9E+10 g/y (GBCSO, 1872)

Gutta percha 9.7E+08 g/y (GBCSO, 1872)

Indigo 3.5E+09 g/y (GBCSO, 1872)

Madder, ground 2.7E+09 g/y (GBCSO, 1872)

root 1.0E+10 g/y (GBCSO, 1872)

Rosin 2.8E+10 g/y (GBCSO, 1872)

Spices

cinnamon 3.5E+08 g/y (GBCSO, 1872)

pepper 5.8E+09 g/y (GBCSO, 1872)

other 3.4E+09 g/y (GBCSO, 1872)

Tea 4.0E+10 g/y (GBCSO, 1872)

Coffee 3.8E+10 g/y (GBCSO, 1872)

Total 1860 import = 6.0E+11 g/y

1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1860 energy of import = 8.6E+15 J/y

16 SUGAR

raw 4.0E+12 g/y (GBCSO, 1872)
refined 1.6E+11 g/y (GBCSO, 1872)
Molasses 1.9E+11 g/y (estimated from GBCSO (1872))
Total 1860 import = 4.3E+12 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 6.7E+16 J/y

17 WOOD & WOOD PRODUCTS

Timber, lumber & wood = 1.4E+12 g/y (GBCSO, 1872)
1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 2.1E+16 J/y

18 CORN AND CORN MEAL

1860 import = 3.6E+11 g/y (GBCSO, 1872)
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 5.2E+15 J/y

19 WHEAT

wheat 1.2E+12 g/y(GBCSO, 1872)
wheat flour 2.3E+09 g/y (GBCSO, 1872)
Total 1860 import = 1.2E+12 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 1.7E+16 J/y

20 COTTON

1860 import = 5.1E+11 g/y (GBCSO, 1872)
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 7.4E+15 J/y

21 FISH & FISH PRODUCTS

fish 2.0E+10 g/y (GBCSO, 1872)
oil 1.5E+10 g/y (GBCSO, 1872)
1860 total = 3.5E+10 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 2.2E+14 J/y

22 ANIMAL PRODUCTS

Bacon & hams 1.6E+08 g/y (GBCSO, 1872)
Beef 1.2E+08 g/y (GBCSO, 1872)
Hair & wool 1.3E+11 g/y (GBCSO, 1872)
Lard 9.0E+09 g/y (GBCSO, 1872)
Pork 7.9E+09 g/y (GBCSO, 1872)
Tallow 6.5E+08 g/y (GBCSO, 1872)
1860 total = 1.5E+11 g/y
1860 energy in imports = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 9.1E+14 J/y

23 IRON, STEEL, & MANUFACTURES OF
bar iron 4.9E+10 g/y (GBCSO, 1872)
other iron & steel 2.4E+09 g/y (GBCSO, 1872)
total import = 5.1E+10 g/y

24 The transformity is a weighted average of the materials in this calculation.
SALTPETER
crude 1.5E+10 g/y(GBCSO, 1872)
cubic niter 3.4E+10 g/y (GBCSO, 1872)
Guano 1.3E+11 g/y (GBCSO, 1872)
total import = 1.8E+11 g/y
ZINC import = 1.7E+10 g/y (GBCSO, 1872)
TIN import = 2.6E+09 g/y (GBCSO, 1872)
BRIMSTONE, CRUDE (Sulfur) import = 4.6E+10 g/y (GBCSO, 1872)
COPPER
metal 1.1E+10 g/y (GBCSO, 1872)
ore (metal content of) 4.7E+10 g/y (GBCSO, 1872)
1860 import = 5.8E+10 g/y
LEAD & manufactures of import = 2.0E+10 g/y (GBCSO, 1872)

25 SERVICES embodied in imports (1860) = 2.1E+08 £/y (GBCSO, 1872)
The emergy-money ratio is that calculated in the 1860 U.S. evaluation, converted from dollars to pounds sterling using the standard $4.9 per 1.0 £.

26 COAL 1860 coal export = 2.1E+17 J/y (estimated from GBCSO(1872))

27 The transformity is a weighted average of the materials in this calculation.
BUTTER & CHEESE
Cheese 1.3E+09 g/y (GBCSO, 1872)
Butter 5.7E+09 g/y(GBCSO, 1872)
1860 export = 7.0E+09 g/y
1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 3.3E+04 J/g (estimated from Odum (1969))
1860 energy of export = 1.8E+14 J/y
OTHER ANIMAL PRODUCTS
Horses 1.6E+09 g/y (estimated from GBCSO(1872))
Leather 2.1E+07 g/y (GBCSO, 1872)
Leather boots & shoes 3.7E+09 g/y (estimated from GBCSO(1872))
Soap 8.9E+07 g/y (GBCSO, 1872)
Wool 5.1E+09 g/y(GBCSO, 1872)
1860 total = 1.0E+10 g/y
1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g* (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in exports = 6.6E+13 J/y

28 FISHERIES PRODUCTS
Herring 3.1E+10 g/y (GBCSO, 1872)
1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in exports = 6.5E+14 J/y

29 IRON EXPORT
Iron, steel & products 6.8E+10 g/y (GBCSO, 1872)
Transformity is the average of pig iron & iron manufactures this study.

30 SERVICES embodied in exports (1860) = 1.6E+08 £/y (GBCSO, 1872)
The emergy money ratio is that calculated for Great Britain in this evaluation.

31 NET EMIGRATION 1860 Net = 1.3E+05 people/y (GBCSO, 1872)
The annual per capita emergy calculated in this evaluation was multiplied by 16 years (an assumed value for the effective maturation, training, and education of an average 1860 emigrant) to obtain the emergy per person conversion used.

APPENDIX F
CALCULATIONS IN SUPPORT OF TABLE 3-19, EMERGY EVALUATION OF THE CONFEDERATE STATES IN 1860.

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term:

1 INSOLATION:

Continental shelf = 1.4E+11 m^2 (assumed 20% of total US shelf)
Farm area 1860 = 7.4E+11 m^2 ((USCO, 1864) excluding WV)
Insolation = 4.6E+09 $J/m^2/y$
Albedo = 3.5E-01 (% given as decimal)
Energy = ((land area) + (shelf area))m^2 * (avg. insolation) J/m^2-y * (1-albedo)
Energy = 2.6E+21 J/y

2 WIND, KINETIC ENERGY = 9.5E+18J/y (estimated from Odum et al. (1987a) for 1860 farm area)

3 RAIN, GEOPOTENTIAL:

Area = 7.4E+15 cm^2
Rainfall = 1.1E+02 cm
Avg. elevation = 4.6E+04 cm
Runoff rate = 8.0E-01 %
Water density = 1.0E+00 g/cm^3
Gravitational constant = 9.8E+02 cm/s^2
Energy = (area) cm^2 * (runoff rate) * (rainfall) cm * (avg. elev.) cm * (water density) g/cm^3
* (gravitational const.) cm/s^2 * 9.96E-08 J/erg
Energy = 3.0E+18 J/y

4 RAIN, CHEMICAL POTENTIAL:

Area = 7.4E+11 m^2
Continental Shelf = 1.4E+11 m^2
Rainfall = 1.1E+00 m/y (estimated
Rain over shelf = 1.0E+00 m/y (estimated
Evapotrans rate = 5.0E-01 (percent given as decimal) (estimated)
Water density = 1.0E+03 kg/j
Gibbs free energy = 4.9E+03 J/kg
Energy over land = (area) m^2 * (Evapotranspiration) * (rainfall) m * (water density) kg/m^3 * (Gibbs no.)J/kg
= 2.1E+18 J/y
Energy over shelf = (area) m^2 * (rainfall) m * (water density) kg/m^3 * (Gibbs free energy) J/kg
= 7.9E+17 J/y
Total energy = 2.9E+18 J/y

5 TIDES:

Continental Shelf = 1.4E+15 cm^2
Mean Tidal Range = 1.2E+02 cm
Density = 1.0E+00 g/cm^3
Numbertides/y = 7.1E+02 (estimated from Odum (1994))
Absorption coefficient = 5.0E-01 (assumed)
Gravitational constant = 9.8E+02 m/s^2
Energy = (shelf area) cm^2 * (absorption coeff.) * (0.5) * (tides/y) * (mean tidal range)^2 $(cm)^2$
* (sea water density) g/cm^3 * (gravitational const.) cm/s^2 * 9.96E-08 J/erg
Energy = 3.6E+17 J/y

6 WAVES: Energy = 1.5E+18 J/y (estimated as 20% of Odum et al. (1987a) for US)

7 EARTH CYCLE:

Land Area = 7.4E+11 m^2
Heat flow/ area = % area stable * heat + % area active * heatflow $J/m^2/y$
Heat flow/area = 1.1E+06 J/m^2-y
Energy = (Land area) m^2 (Heat flow per unit area) J/m^2-y
Energy = 8.1E+17 J/y

8 FORESTRY:

1859 harvest = 5.5E+16 J/y (estimated from Steers (1948) and adjusted for CSA/USA population ratio)

9 FUELWOOD USE:

1860 use = 6.6E+17 J/y (USDC (1975) adjusted for CSA population as percent of population of USA)

10 HYDROPOWER:

1860 Hydropower = 1.9E+15 J/y (estimated from USA 1860 evaluation for the percentage of manufacturing labor, capital, and raw material in CSA)

11 PLANT LEAF, FIBER, & PRODUCTS

1860 Hay = 9.9E+11 g/y (USCO, 1864)
1860 Flax = 3.2E+08 g/y (USCO, 1864)
1860 Hemp = 5.4E+09 g/y (USCO, 1864)
1860 Tobacco = 9.3E+10 g/y (USCO, 1864)
1860 total production = 1.1E+12 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.6E+16 J/y

12 BREADSTUFFS & GRAINS

1860 Barley = 2.9E+09 g/y (estimated from USCO (1864))
1860 Buckwheat = 7.3E+09 g/y (estimated from USCO (1864))
1860 Clover seed = 6.5E+08 g/y (estimated from USCO (1864))
1860 Flaxseed = 8.6E+08 g/y (estimated from USCO (1864))
1860 Grass seeds = 1.5E+09 g/y (estimated from USCO (1864))
1860 Indian corn = 3.8E+12 g/y (estimated from USCO (1864))
1860 Oats = 2.7E+11 g/y (estimated from USCO (1864))
1860 Peas & beans = 1.6E+11 g/y (estimated from USCO (1864))
1860 Rice = 8.5E+10 g/y (USCO, 1864)
1860 Rye = 3.0E+12 g/y (estimated from USCO (1864))
1860 Wheat = 3.5E+11 g/y (estimated from USCO (1864))
1860 total production = 7.6E+12 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.2E+17 J/y

13 FRUIT & ROOT CROPS

1860 Hops = 6.7E+06 g/y(USCO, 1864)
1860 Irish potatoes = 9.0E+10 g/y (estimated from USCO (1864))
1860 Sweet potatoes = 5.2E+11 g/y (estimated from USCO (1864))
1860 total production = 6.1E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 2.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 2.5E+15 J/y

14 GINNED COTTON

Production = 9.7E+11 g/y (estimated from USCO (1864))
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.4E+16 J/y

15 SUGAR & MOLASSES
1860 Cane molasses = 4.8E+10 g/y (estimated from USCO (1864))
1860 Cane sugar = 7.3E+11 g/y (USCO, 1864)
1860 Maple molasses = 6.1E+08 g/y (estimated from USCO (1864))
1860 Maple sugar = 4.6E+08 g/y (USCO, 1864)
1860 Sorghum molasses = 5.2E+09 g/y (estimated from USCO (1864))
1860 total production = 7.9E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.0E+16 J/y

16 SHELLFISH FISHERIES: Energy of catch = 1.4E+13 J/y (estimated from USCO (1864) as 40% of USA catch)

17 BUTTER & CHEESE
1860 Butter = 2.7E+10 g/y (USCO, 1864)
1860 Cheese = 3.7E+08 g/y (USCO, 1864)
1860 total production = 2.7E+10 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 3.3E+04 J/g (estimated from Odum (1969))
1860 energyof prod. = 6.9E+14 J/y

18 FINFISH FISHERIES: Energy of catch = 5.1E+12 J/y (estimated from USCO (1864) as 10% of USA catch)

19 LIVESTOCK PRODUCTION:
1860 cattle prod.= 1.4E+11 g/y (estimated from USCO (1864))
1860 swine prod.= 2.1E+11 g/y (estimated from USCO (1864))
1860 sheep prod.= 1.5E+10 g/y (estimated from USCO (1864))
1860 horse prod.= 8.7E+10 g/y (estimated from USCO (1864))
1860 mule prod.= 4.1E+10 g/y (estimated from USCO (1864))
1860 total prod= 4.9E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 3.1E+15 J/y

20 WOOL
1860 Wool = 4.5E+09 g/y (USCO, 1864)
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 7.1E+13 J/y

21 SOIL LOSS
1860 improved farm land = 1.9E+07 ha (USCO (1864), excludes farms in West Virginia)
Soil loss / improved ha = 1.5E+07 g/ha-y (estimated)
1860 total soil loss = 2.9E+14 g/y
Energy in soil loss = (Total loss) g/y * (% Organic matter) * (Energy / g organic matter) J/g *
(dry weight / wet weight) g/g
% Organic matter = 3.25 % (estimated from Brady (1990))
Energy/g organic matter = 2.3E+04 J/g (estimated)
Dry weight/wet weight = 5.0E-01 g-dry/g-wet (estimated)
1860 energy in soil loss = 1.1E+17 J/y

22 COAL 1860 extraction (bituminous) = 1.8E+16 J/y(USCO, 1862)

23 IRON, ore 1860 extraction = 6.7E+10 g/y (USCO, 1862)

24 COPPER 1860 extraction = 6.0E+09 g/y (USCO, 1862)

25 LEAD 1860 extraction = 7.2E+08 g/y (estimated from USCO (1862))

26 FRUITS, GREEN, RIPE OR DRIED
Total 1860 import = 1.1E+09 g/y (USTD, 1860)
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 5.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 9.6E+12 J/y

OTHER PLANT PRODUCTS

Nuts 1.9E+08 g/y (USTD, 1860)
Coffee 3.5E+10 g/y (USTD, 1860)
Total 1860 import = 3.5E+10 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 5.1E+14 J/y

SUGAR

brown 8.3E+09 g/y (USTD, 1860)
white, clayed, or powdered 1.3E+08 g/y (USTD, 1860)
Molasses 1.5E+10 g/y (estimated from USTD, 1860)
Total 1860 import = 2.4E+10 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 3.6E+14 J/y

27 GRAINS & BREADSTUFFS

Indian corn imported from western USA 2.1E+10 g/y (from Fishlow's (1964) New Orleans 1859-1861 estimates)
Flour imported from western USA 2.6E+10 g/y (from Fishlow's (1964) New Orleans 1859-1861 estimates)
1860 total import = 4.7E+10 g/y
1860 energy of import = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 7.1E+14 J/y

28 ANIMAL PRODUCTS

Pork imported from western USA 6.24E+09 g/y (from Fishlow's (1964) New Orleans 1859-1861 estimates)
Bacon imported from western USA 3.81E+09 g/y (from Fishlow's (1964) New Orleans 1859-1861 estimates)
Beef imported from western USA 9.59E+08 g/y (from Fishlow's (1964) New Orleans 1859-1861 estimates)
Lard imported from western USA 1.07E+09 g/y (from Fishlow's (1964) New Orleans 1859-1861 estimates)
1860 total imports = 1.21E+10 g/y
1860 energy in imports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.00E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.09E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 7.57E+13 J/y

29 ASH & SODA, Plant derived, total import = 2.76E+09 g/y (USTD, 1860)

30 IRON, STEEL, & MANUFACTURES OF

bar iron & other 7.33E+09 g/y (USTD, 1860)
nails, spikes, & tacks 2.76E+08 g/y (USTD, 1860)
old & scrap 2.17E+08 g/y (USTD, 1860)
pig 7.27E+09 g/y (USTD, 1860)
rod 1.49E+08 g/y (USTD, 1860)
sheet iron 6.19E+08 g/y (USTD, 1860)
steel 6.12E+08 g/y (USTD, 1860)
anchors & other 2.04E+09 g/y (USTD, 1860)
railroad 5.93E+10 g/y (USTD, 1860)
total import = 7.78E+10 g/y

31 LEAD & MANUFACTURES OF

bar, pig, pipes, sheet, & old 2.15E+07 g/y (USTD, 1860)

32 COIN, GOLD 1860 import = 6.13E+05 g/y (estimated from USTD, 1860)

33 COIN, SILVER 1860 import = 2.77E+07 g/y (estimated from USTD, 1860)

34 HUMAN SERVICES IN IMPORTS NOT ACCOUNTED FOR IN TRANSFORMITIES USED ABOVE

Services in imports (1860) = 2.80E+07 $/y (USTD, 1860)
less imports w/ labor in transformity 7.60E+05 $/y
unaccounted for services = 2.72E+07 $/y

The emergy-money ratio is that calculated in the 1860 Great Britain evaluation, converted from pounds sterling using the standard $4.9 per 1.0 £.

35 UNCOUNTED HUMAN SERVICES IN IMPORTS FROM THE FEDERAL STATES (USA)

Total northern imports = 2.6E+08 $/y (Fishlow, 1964)
services accounted for above = 6.2E+06 $/y (from above and Fishlow (1964))
Uncounted services in northern imports = 2.5E+08 $/y

The emergy-money ratio is that calculated in the 1860 Federal states evaluation.

36	PLANT LEAF & FIBER PRODUCTS		
	Cables & cordage	6.40E+06	g/y (USTD, 1860)
	Manufactured tobacco	1.88E+08	g/y (USTD, 1860)
	Tobacco leaf	1.21E+10	g/y (USTD, 1860)
	1860 total export =	1.23E+10	g/y
	1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	8.50E-01	g dry/g wet (estimated from Crampton and Harris (1969))
	energy/g =	1.70E+04	J/g (estimated from Odum (1969))
	1860 energy of export =	1.78E+14	J/y
	GRAINS & BREADSTUFFS		
	Biscuit or ship bread	4.38E+08	g/y (estimated from USTD (1860))
	Flaxseed	3.54E+05	g/y (estimated from USTD (1860))
	Indian corn	4.36E+09	g/y (estimated from USTD (1860))
	Indian corn meal	1.53E+08	g/y (estimated from USTD (1860))
	Rice	9.00E+09	g/y (estimated from USTD (1860))
	Wheat	5.64E+08	g/y (estimated from USTD (1860))
	Wheat flour	3.30E+10	g/y (estimated from USTD (1860))
	1860 total export=	4.75E+10	g/y
	1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	9.00E-01	g dry/g wet (estimated from Crampton and Harris (1969))
	energy/g =	1.70E+04	J/g (estimated from Odum (1969))
	1860 energy of export =	7.26E+14	J/y
37	WOOD & WOOD PRODUCTS		
	Hewn timber	2.92E+10	g/y (USTD, 1860)
	Lumber, other	1.05E+10	g/y (USTD, 1860)
	Shingles	2.70E+12	g/y (estimated from USTD (1860))
	Staves and heading	3.04E+06	g/y (estimated from USTD (1860))
	1860 total export =	2.74E+12	g/y
	1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	9.00E-01	g dry/g wet (estimated from Crampton and Harris (1969))
	energy/g =	1.70E+04	J/g (estimated from Odum (1969))
	1860 energy in exports =	4.19E+16	J/y
38	COAL		
	1860 export =	3.84E+13	J/y (from USTD (1860))
39	COTTON		
	1860 export =	8.02E+11	g/y (USTD, 1860)
	1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	8.50E-01	g dry/g wet (estimated from Crampton and Harris (1969))
	energy/g =	1.70E+04	J/g (estimated from Odum (1969))
	1860 energy of export =	1.16E+16	J/y
40	BUTTER & CHEESE		
	Cheese	4.12E+07	g/y (USTD, 1860)
	Butter	5.03E+07	g/y (USTD, 1860)
	1860 export =	9.15E+07	g/y
	1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	7.50E-01	g dry/g wet (estimated from Crampton and Harris (1969))
	energy/g =	3.35E+04	J/g (estimated from Odum (1969))
	1860 energy of export =	2.30E+12	J/y
	OTHER ANIMAL PRODUCTS		
	Beef	5.17E+08	g/y (estimated from USTD (1860))
	Hams & bacon	4.27E+08	g/y (USTD, 1860)
	Horned cattle	5.05E+08	g/y (estimated from USTD (1860))
	Horses	1.44E+08	g/y (estimated from USTD (1860))
	Lard	5.11E+09	g/y (USTD, 1860)
	Lard oil	3.99E+09	g/y (estimated from USTD (1860))
	Pork	4.15E+08	g/y (estimated from USTD (1860))
	Tallow	8.93E+08	g/y (USTD, 1860)
	1860 total =	1.20E+10	g/y
	1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g		
	dry-wt/wet-wt =	3.00E-01	g dry/g wet (estimated from Crampton and Harris (1969))
	energy/g =	2.09E+04	J/g (estimated from Odum (1969))
	1860 energy in exports =	7.52E+13	J/y

41 IRON & MANUFACTURES OF IRON

bar	1.29E+07	g/y (USTD, 1860)
castings	3.86E+06	g/y (USTD, 1860)
nails	2.97E+07	g/y (USTD, 1860)
pig	0.00E+00	g/y (USTD, 1860)
total export =	4.65E+07	g/y

42 GOLD & SILVER COIN 3.07E+05g/y (estimated from USTD (1860))

43 HUMAN SERVICES NOT ACCOUNTED FOR IN TRANSFORMITIES USED ABOVE

Total services in exports (1860) =	2.61E+08	$/y (USTD, 1860)
exports w/ transformities including labor =	1.79E+08	$/y
remaining exports =	8.18E+07	$/y

44 HUMAN SERVICES IN EXPORTS TO THE FEDERAL STATES (USA)

Services in Northern exports =	9.0E+07	$/y (Fishlow, 1964)

APPENDIX G
CALCULATIONS IN SUPPORT OF TABLE 3-22, CHANGES IN THE EMERGY EVALUATION OF THE CONFEDERATE STATES FROM 1861 TROUGH 1865.

Unless otherwise stated, the energy calculations and transformities used are from the corresponding terms in Table 3-19 and Appendix F.

<u>term:</u>

12 1861 BREADSTUFFS & GRAINS

1861 Indian corn = 4.5E+12 g/y (from Gates (1965))
1861 Wheat = 6.1E+11 g/y (from Gates (1965))
1861 energy of prod. = 7.8E+16 J/y

1862 BREADSTUFFS & GRAINS

1862 Indian corn = 4.1E+12 g/y (from Gates (1965))
1862 Wheat = 4.8E+11 g/y (from Gates (1965))
1862 energy of prod. = 7.0E+16 J/y

1863 BREADSTUFFS & GRAINS

1863 Indian corn = 4.8E+12 g/y (from Gates (1965))
1863 Wheat = 7.5E+11 g/y (from Gates (1965))
1863 energy of prod. = 8.4E+16 J/y

13 FRUIT & ROOT CROPS

1861 Potatoes = 2.9E+15 J/y (from Gates (1965))
1862 Potatoes = 2.3E+15 J/y (from Gates (1965))
1863 Potatoes = 3.5E+15 J/y (from Gates (1965))

14 GINNED COTTON

1861 production = 1.2E+16 J/y (from Burton and Bonnin (1993))
1862 production = 3.9E+15 J/y (from Burton and Bonnin (1993))
1863 production = 1.3E+15 J/y (from Burton and Bonnin (1993))
1864 production = 7.9E+14 J/y (from Burton and Bonnin (1993))

15 SUGAR & MOLASSES

1864 total production = 4.4E+09 g/y (Sitterson, 1993)
1864 energy of prod. = 5.6E+13 J/y

23 IRON ORE

Niter & Mining Bureau receipts 1/1/63-9/30/64 = 1.9E+10 g (to September 30, 1864 (ORUCA))
receipts for other periods = 1.7E+10 g (estimated as 90% of 1/1/63-9/30/64)
total = 3.5E+10 g

24 COPPER

Total extraction = 3.5E+08 g (to September 30, 1864 (ORUCA, 4-3))
Refined transformity is from Sundberg et al. (In Press)

25 LEAD

Extraction, 1/1/1863-1/1/1865 = 1.0E+09 g (ORUCA, 4-3)
Production in 1861, 1862, & 1865 = 6.1E+08 g (estimated as 60% of 1/1/63-1/1/65 production)
Total production, 1861-1865 = 1.6E+09 g
Transformity is the lead pig transformity calculated in this study.

28 ANIMAL PRODUCTS (MEAT)

11/1/63-10/25/64 import 2.81E+09 g (ORUCA, 4-3)
Estimated import for other periods 4.22E+09 g (estimated as 150% of 11/1/63-10/25/64 import)
total energy in import = 1.44E+16 J

30 IRON, STEEL, & MANUFACTURES OF

muskets & rifles 1.63E+09 g (estimated from Wise (1988) assuming 9#/piece weight)
side arms 2.64E+08 g (estimated)
total import = 1.90E+09 g

30b SALTPETER (KNO3)

Total import, 1861 - 1865 = 1.02E+09 g (Wise, 1988)

31 LEAD

Total import, 1861 - 1865 = 1.36E+09 g (Wise, 1988)

34a TOTAL SERVICES IN FOREIGN IMPORTS THROUGH THE BLOCKADE (1860 - 1865)

Total tonnage of vessels with foreign cargoes arriving in Confederate states, 1861-1865
= 1.00E+06 tons (estimated from Wise (1988) for 1000 successful trips of vessels assumed to be 1000 tons)
Services embodied in foreign imports to Confederate states in 1860
= 2.8E+07 $/y (USTD, 1862)
Total tonnage of vessels arriving in Confederate states in 1860
= 7.2E+06 tons/y (USTD, 1862)
Estimated human services embodied in imports through the blockade ($) = (tonnage, 1861-1865) tons * (Services in imports 1860) $/y / ((tonnage, 1860) tons/y
Estimated services embodied in imports through blockade (1861-1865)
= 3.9E+06 $

This is an estimate of the total human services embodied in imports run through the blockade. The emergy-money ratio used is that calculated in the Great Britain 1860 evaluation.

35a SERVICES IN IMPORTS FROM UNION

39 COTTON

Total 1861 - 1865 export = 1.05E+15 J (from Wise (1988))

43a TOTAL SERVICES IN EXPORTS (1861-1865)

total export of cotton = 4.00E+05 bales (Wise (1988))
1860 price of cotton = 43.44 $/bale (from USDC (1975))
value of exported cotton in 1860 prices = 1.74E+07 $

This is an approximation of exported services that assumes the only major export was cotton. The emergy-money ratio used is from USA 1860 evaluation.

44a TOTAL SERVICES IN EXPORTS TO UNION STATES

APPENDIX H
CALCULATIONS IN SUPPORT OF TABLE 3-23, EMERGY EVALUATION OF THE UNION STATES IN 1860.

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term:

1 INSOLATION

Continental shelf= 7.0E+10 m^2 (assumed 10% of total U.S. shelf)
Farm area 1860 = 1.5E+12 m^2 (USCO (1864), includes WV)
Insolation = 4.6E+09 J/m^2/y
Albedo = 3.5E-01 (% given as decimal)
Energy = ((land area) + (shelf area))m^2 * (avg. insolation) J/m^2-y * (1-albedo)
Energy = 2.9E+21 J/y

2 WIND, KINETIC ENERGY Energy = 1.8E+19 J/y (estimated from Odum et al. (1987a) for 1860 farm area)

3 RAIN, GEOPOTENTIAL ENERGY

Area = 9.1E+15 cm^2
Rainfall = 1.1E+02 cm
Avg. elevation = 4.6E+04 cm
Runoff rate = 8.0E-01 %
Water density = 1.0E+00 g/cm^3
Gravitational constant = 9.8E+02 cm/s^2
Energy = (area) cm^2 * (runoff rate) * (rainfall) cm * (avg. elev.) cm * (water density) g/cm^3
* (gravitational const.) cm/s^2 * 9.96E-08 J/erg
Energy = 3.8E+18 J/y

4 RAIN, CHEMICAL POTENTIAL ENERGY

Area = 9.1E+11 m^2
Continental Shelf= 7.0E+10 m^2
Rainfall = 1.1E+00 m/y (estimated)
Rain over shelf = 1.0E+00 m/y (estimated)
Evapotrans rate = 5.0E-01 (percent given as decimal) (estimated)
Water density = 1.0E+03 kg/j
Gibbs free energy = 4.9E+03 J/kg
Energy over land = (area) m^2 * (Evapotranspiration) * (rainfall) m * (water density) kg/m^3 * (Gibbs free energy) J / kg
= 2.6E+18 J/y
Energy over shelf= (area) m^2 * (rainfall) m * (water density)kg/m^3 *(Gibbs no.)J/kg
= 3.9E+17 J/y
Total energy = 3.0E+18 J/y

5 TIDAL ENERGY ABSORBED

Continental Shelf= 7.0E+14 cm^2
Mean Tidal Range = 1.2E+02 cm
Density = 1.0E+00 g/cm^3
Number tides/y = 7.1E+02 (estimated from Odum (1994))
Absorption coeff.= 5.0E-01 (assumed)
Gravitational constant = 9.8E+02 m/s^2
Energy = (shelf area) cm^2 * (absorption coeff.) * (0.5) * (tides/y) * (mean tidal range)^2 (cm)^2
*(sea water density) g/cm^3 * (gravitational const.) cm/s^2 *9.96E-08 J/erg
Energy = 1.8E+17 J/y

6 WAVE ENERGY Energy = 1.5E+18 J/y (estimated as 20% of Odum et al. (1987a) for US)

7 EARTH CYCLE:
Land Area = 9.1E+11 m^2
Heat flow / area = % area stable * heat + % area active * heat flow $J/m^2/y$
Heat flow/area = 1.1E+06 J/m^2-y
Energy = (Land area) m^2 (Heat flow per unit area) J/m^2-y
Energy = 1.0E+18 J/y

8 FORESTRY:
1859 harvest 1.4E+17 J/y (estimated from Steers (1948) and adjusted for the CSA/USA population ratio)

9 FUELWOOD USE:
1860 use = 1.7E+18 J/y (USDC (1975) adjusted for Union population as percent of USA)

10 HYDROPOWER: 1860 Hydropower = 1.9E+16 J/y (estimated from USA 1860 evaluation for the percentage of manufacturing labor, capital, in the North)

11 PLANT LEAF, FIBER, & PRODUCTS
1860 Hay = 1.6E+13 g/y (USCO, 1864)
1860 Flax = 1.8E+09 g/y (USCO, 1864)
1860 Hemp, dew rotted = 6.2E+10 g/y (USCO, 1864)
1860 Tobacco = 1.0E+11 g/y (USCO, 1864)
1860 total production = 1.6E+13 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 2.4E+17 J/y

12 BREADSTUFFS & GRAINS
1860 Barley = 2.1E+11 g/y (estimated from USCO (1864))
1860 Buckwheat = 2.3E+11 g/y (estimated from USCO (1864))
1860 Clover seed = 1.2E+10 g/y (estimated from USCO (1864))
1860 Flaxseed = 6.9E+09 g/y (estimated from USCO (1864))
1860 Grass seeds = 1.1E+10 g/y (estimated from USCO (1864))
1860 Indian corn = 7.6E+12 g/y (estimated from USCO (1864))
1860 Oats = 2.1E+12 g/y (estimated from USCO (1864))
1860 Peas & beans = 4.8E+10 g/y (estimated from USCO (1864))
1860 Rice = 7.6E+07 g/y (USCO, 1864)
1860 Rye = 2.6E+11 g/y (estimated from USCO (1864))
1860 Wheat = 2.0E+12 g/y (estimated from USCO (1864))
1860 total production = 1.2E+13 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.9E+17 J/y

13 FRUIT & ROOT CROPS
1860 Hops = 5.0E+09 g/y (USCO, 1864)
1860 Irish potatoes = 1.4E+12 g/y (estimated from USCO (1864))
1860 Sweet potatoes = 5.7E+10 g/y (estimated from USCO (1864))
1860 total production = 1.5E+12 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 2.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 6.2E+15 J/y

14 GINNED COTTON 1860 production = 8.5E+09 g/y (estimated from USCO (1864))
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 1.2E+14 J/y

15 SUGAR & MOLASSES

1860 Maple molasses = 4.5E+09 g/y (estimated from USCO (1864))
1860 Maple sugar = 1.8E+10 g/y (USCO, 1864)
1860 Sorghum molasses = 1.6E+10 g/y (estimated from USCO (1864))
1860 total production = 3.8E+10 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 5.0E+14 J/y

16 SHELLFISH FISHERIES:

Energy of 1860 shellfish catch = (catch)g-live wt * (g-dry/g-live) * (J/g-dry)
1860 shellfish catch = 3.9E+09 g/y (estimated from USCO (1864) as 60% of USA catch)
g-dry/g-live = 2.6E-01 g-dry/g-live (estimated from NRC (1971))
J/g-dry = 2.1E+04 J/g-dry (estimated from Odum (1969))
Energy of catch = 2.1E+13 J/y

17 BUTTER & CHEESE

1860 Butter = 1.8E+11 g/y (USCO, 1864)
1860 Cheese = 4.7E+10 g/y (USCO, 1864)
1860 total production = 2.3E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 3.3E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 5.7E+15 J/y

18 FINFISH FISHERIES:

Energy of 1860 fish catch = (catch)g-live wt * (g-dry/g-live) * (J/g-dry)
1860 fish catch = 8.4E+09 g/y (estimated from USCO (1864) as 90% of USA catch)
g-dry/g-live = 2.6E-01 g-dry/g-live (estimated from NRC (1971))
J/g-dry = 2.1E+04 J/g-dry (estimated from Odum (1969))
Energy of catch = 4.5E+13 J/y

19 LIVESTOCK PRODUCTION:

1860 cattle prod.= 2.1E+11 g/y (estimated from USCO (1864))
1860 swine prod.= 2.9E+11 g/y (estimated from USCO (1864))
1860 sheep prod.= 6.6E+10 g/y (estimated from USCO (1864))
1860 horse prod.= 2.3E+11 g/y (estimated from USCO (1864))
1860 mule prod.= 1.7E+10 g/y (estimated from USCO (1864))
1860 total prod= 8.1E+11 g/y
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 5.1E+15 J/y

20 WOOL

1860 Wool = 2.7E+10 g/y (USCO, 1864)
1860 energy of production = (production) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 7.5E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy of prod. = 4.3E+14 J/y

21 SOIL LOSS

1860 improved farm land = 4.7E+07 ha (USCO, 1864)
Soil loss / improved ha = 1.5E+07 g/ha-y (estimated)
1860 total soil loss = 7.0E+14 g/y
Energy in soil loss = (Total loss) g / y * (% Organic matter) *(Energy / g organic matter) J / g * (dry weight / wet weight) g/g
% Organic matter = 3.25 % (estimated from Brady (1990))
Energy/g organic matter = 2.3E+04 J/g (estimated)
Dry weight/wet weight = 5.0E-01 g-dry/g-wet (estimated)
1860 energy in soil loss = 2.6E+17 J/y

22 COAL

1859-60 extraction
bituminous = 1.5E+17 J/y(USCO, 1864)
anthracite = 2.2E+17 J/y (USCO, 1864)
total = 3.7E+17 J/y

23 CRUDE PETROLEUM:
1860 extraction = 5.0E+05 bbl/y (Rothwell, 1892)
6.1E+09 J/bbl (Shonka, 1979)
Energy (J/y) = (bbl/y) * (J/bbl)
Energy = 3.1E+15 J/y

24 IRON ORE (Fe) 1860 extraction = 2.4E+12 g/y (Rothwell, 1892)
Transformity is the average of those for iron pig and iron products (this study).

25 COPPER ORE (Cu) 1860 extraction = 8.6E+09 g/y (U.S. Census Office, 1860)

26 NICKEL ORE (Ni) 1860 extraction = 2.4E+09 g/y (U.S. Census Office, 1860)

27 LEAD ORE (Pb) 1860 extraction = 1.1E+10 g/y (U.S. Census Office, 1860)
Transformity is the lead pig transformity calculated in this study.

28 ZINC ORE (Zn) 1860 extraction = 1.2E+10 g/y (U.S. Census Office, 1860)

29 MERCURY (Hg) 1860 extraction = 1.0E+08 g/y (Rothwell, 1892)

30 SILVER: (Ag) 1860 extraction 1.2E+05 troy oz/y (Rothwell, 1892)
3.1E+01 g/troy oz
3.6E+06 g/y

31 GOLD (Au) 1860 extraction 6.9E+07 g/y (Rothwell, 1892)

32 The transformity is a weighted average of the plant products in this calculation.

FRUITS, GREEN, RIPE OR DRIED

currants	1.5E+09	g/y (USTD, 1860)
dates	1.4E+09	g/y (USTD, 1860)
figs	3.4E+09	g/y (USTD, 1860)
plums	4.1E+06	g/y (USTD, 1860)
prunes	2.3E+08	g/y (USTD, 1860)
raisins	1.1E+10	g/y (USTD, 1860)
Total 1860 import =	1.9E+10	g/y

1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 5.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 1.6E+14 J/y

PLANT LEAF, BARK, & FIBER & INSECT PRODUCTS

Arrowroot	8.8E+07	g/y (USTD, 1860)
Bristles	2.8E+08	g/y (USTD, 1860)
Camphor, crude	2.2E+07	g/y (USTD, 1860)
Bark, quilla	1.0E+06	g/y (USTD, 1860)
all other kinds not otherwise detailed	1.2E+07	g/y (USTD, 1860)
Cochineal	1.3E+08	g/y (USTD, 1860)
Cocoa	1.4E+09	g/y (USTD, 1860)
Gums	2.8E+09	g/y (USTD, 1860)
Indigo	7.7E+08	g/y (USTD, 1860)
Licorice, paste	2.4E+09	g/y (USTD, 1860)
Licorice, root	1.2E+09	g/y (USTD, 1860)
Nuts	1.1E+09	g/y (USTD, 1860)
Spices		
cassia	7.7E+08	g/y (USTD, 1860)
cinnamon	1.9E+07	g/y (USTD, 1860)
cloves	2.4E+08	g/y (USTD, 1860)
ginger	5.0E+08	g/y (USTD, 1860)
mace	2.1E+07	g/y (USTD, 1860)
nutmegs	2.3E+08	g/y (USTD, 1860)
pepper, red	3.8E+09	g/y (USTD, 1860)
black	4.2E+07	g/y (USTD, 1860)
pimento	7.3E+08	g/y (USTD, 1860)
Cordage, tarred and cables	5.6E+08	g/y (USTD, 1860)
un tarred	2.1E+08	g/y (USTD, 1860)
Tea	1.2E+10	g/y (USTD, 1860)
Coffee	4.7E+10	g/y (USTD, 1860)
Total 1860 import =	7.7E+10	g/y

1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 1.1E+15 J/y

SUGAR

brown 2.9E+11 g/y (USTD, 1860)
candy 1.6E+07 g/y (USTD, 1860)
loafed & other refined 3.5E+08 g/y (USTD, 1860)
syrup of sugar cane 3.9E+07 g/y (estimated from USTD, 1860)
white, clayed, or powdered 3.4E+08 g/y (USTD, 1860)
Molasses 8.3E+10 g/y (estimated from USTD, 1860)
Total 1860 import = 3.8E+11 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
1860 energy of import = 5.8E+15 J/y

33 COAL 1860 coal import = 6.7E+15 J/y (estimated from USTD (1860))

34 COTTON total 1860 import = 2.5E+15 J/y (estimated from USA 1860 evaluation for total domestic production & exports (including both Union & Confederate figures) and from USTD (1860) for foreign imports)

35 FISH, DRIED, SMOKED OR PICKLED

dried or smoked 3.0E+09 g/y (estimated from USTD, 1860)
herring 5.0E+08 g/y (estimated from USTD, 1860)
mackerel 5.3E+06 g/y (estimated from USTD, 1860)
salmon 3.6E+05 g/y (estimated from USTD, 1860)
all other 6.9E+07 g/y (USTD, 1860)
1860 total = 3.6E+09 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 2.2E+13 J/y

36 WHALE PRODUCTS OF OFFSHORE & FOREIGN FISHERIES

sperm oil 7.0E+09 g/y (estimated from USCO (1864))
whale oil 1.3E+10 g/y (estimated from USCO (1864))
whale bone 6.1E+08 g/y (estimated from USCO (1864))
Total import & landing = 2.1E+10 g/y
1860 energy of import = (import) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in imports = 1.3E+14 J/y

37 PLANT DERIVED ASH & SODA

Barilla 3.7E+08 g/y (USTD, 1860)
Soda, ash 3.8E+10 g/y (USTD, 1860)
Soda, carbonate 7.7E+09 g/y (USTD, 1860)
Soda, sal. 2.3E+09 g/y (USTD, 1860)
1860 total import = 4.9E+10 g/y

38 IRON, STEEL, & MANUFACTURES OF

bar iron 8.9E+10 g/y (USTD, 1860)
hoop iron 1.1E+09 g/y (USTD, 1860)
nails, spikes, & tacks 3.4E+08 g/y (USTD, 1860)
old & scrap 8.1E+09 g/y (USTD, 1860)
pig 5.8E+10 g/y (USTD, 1860)
rod 3.8E+10 g/y (USTD, 1860)
sheet iron 1.3E+10 g/y(USTD, 1860)
steel 1.8E+10 g/y (USTD, 1860)
wire, cap & bonnet 1.1E+08 g/y (USTD, 1860)
cables, chain 2.3E+09 g/y (USTD, 1860)
anvils & anvil parts 3.4E+08 g/y (USTD, 1860)
muskets & rifles 1.1E+07 g/y (estimated from USTD, 1860)
railroad & other 5.0E+10 g/y (USTD, 1860)
total import = 2.9E+11 g/y

39 The transformity is a weighted average of the materials in this calculation.
CHALK import = 9.2E+09 g/y (USTD, 1860)
BRIMSTONE crude (Sulfur)= 1.6E+10 g/y (USTD, 1860)

LEAD & MANUFACTURES OF

bar, pig, sheet, & old	1.9E+10	g/y (USTD, 1860)
pipes	7.9E+06	g/y (USTD, 1860)
Total import =	1.9E+10	g/y

40 COIN, SILVER import = 6.3E+07 g/y (estimated from USTD (1860))

41 COIN, GOLD import = 1.5E+06 g/y (estimated from USTD (1860))

42 HUMAN SERVICES IN FOREIGN EXPORTS NOT ACCOUNTED FOR IN TRANSFORMITIES USED ABOVE

embodied in imports (1860) = 3.3E+08 $/y (USTD, 1860)

services accounted for in transformities of products in terms above

= 1.6E+07 $/y

services embodied in imports that are not accounted for above

= 3.2E+08 $/y

The emergy-money ratio is that calculated in the 1860 Great Britain evaluation, converted from pounds sterling using the standard $4.9 per 1.0 £.

43 HUMAN SERVICES IN IMPORTS FROM THE CONFEDERATE STATES (CSA)

Services in imports from CSA = 9.0E+07 $/y (Fishlow, 1964)

44 NET IMMIGRATION

1860 immigration = 1.5E+05 people/y (USDC ,1975)

The annual per capita emergy calculated in the 1860 Great Britain evaluation was multiplied by 16 years (an assumed value for the effective maturation, training, and education of an average 1860 immigrant) to obtain the emergy per person conversion used. The majority of 1860 immigrants were from Great Britain.

45 The transformity is a weighted average of the materials in this calculation.

PLANT LEAF & FIBER PRODUCTS

Cables & cordage	1.3E+09	g/y (USTD, 1860)
Hemp	1.7E+08	g/y (USTD, 1860)
Snuff	1.8E+07	g/y (USTD, 1860)
Manufactured tobacco	7.8E+09	g/y (USTD, 1860)
Tobacco leaf	1.3E+10	g/y (USTD, 1860)
Coffee (foreign product)	9.1E+09	g/y (USTD, 1860)
Tea (foreign product)	2.4E+09	g/y (USTD, 1860)
Cocoa (foreign product)	9.1E+08	g/y (USTD, 1860)
Dried fruit (foreign product)	1.2E+09	g/y (USTD, 1860)
1860 total export =	3.6E+10	g/y

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 8.5E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1860 energy of export = 5.3E+14 J/y

GRAINS & BREADSTUFFS

Biscuit or ship bread	1.2E+10	g/y (estimated from USTD (1860))
Clover seed	1.6E+09	g/y (estimated from USTD (1860))
Flaxseed	3.7E+07	g/y (estimated from USTD (1860))
Indian corn	4.1E+10	g/y (from USTD (1860))
Indian corn meal	2.1E+10	g/y (from USTD (1860))
Rice	9.3E+09	g/y (from USTD (1860))
Rye meal	1.0E+09	g/y (from USTD (1860))
Wheat	5.6E+10	g/y (from USTD (1860))
Wheat flour	2.0E+11	g/y (from USTD (1860))
1860 total export =	3.5E+11	g/y

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton & Harris (1969))

energy/g = 1.7E+04 J/g (estimated from Odum (1969))

1860 energy of export = 5.3E+15 J/y

46 WOOD & WOOD PRODUCTS

Boards, plank, & scantling	1.0E+12	g/y (estimated from USTD (1860))
Hewn timber	1.6E+08	g/y (USTD, 1860)
Lumber, other	7.9E+10	g/y (USTD, 1860)
Shingles	2.0E+12	g/y (estimated from USTD (1860))
Staves and heading	1.7E+10	g/y (estimated from USTD (1860))
1860 total export =	3.1E+12	g/y

1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	9.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	1.7E+04	J/g (estimated from Odum (1969))
1860 energy in exports =	4.8E+16	J/y

47 COAL

1860 export =	5.2E+15	J/y (estimated from USTD (1860))

48 COTTON

1860 export =	4.0E+10	g/y (USTD, 1860)

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	8.5E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	1.7E+04	J/g (estimated from Odum (1969))
1860 energy of export =	6.0E+14	J/y

49 The transformity is a weighted average of the materials in this calculation.

BUTTER & CHEESE

Cheese	7.0E+09	g/y (USTD, 1860)
Butter	3.4E+09	g/y (USTD, 1860)
1860 export =	1.0E+10	g/y

1860 energy of export = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	7.5E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	3.3E+04	J/g (estimated from Odum (1969))
1860 energy of export =	2.6E+14	J/y

OTHER ANIMAL PRODUCTS

Adamantine & other candles	2.2E+09	g/y (USTD, 1860)
Beef	1.6E+10	g/y (estimated from USTD (1860))
Hams & bacon	1.1E+10	g/y (USTD, 1860)
Hogs	7.3E+09	g/y (estimated from USTD (1860))
Horned cattle	3.6E+09	g/y (estimated from USTD (1860))
Horses	6.7E+08	g/y (estimated from USTD (1860))
Lard	9.2E+09	g/y(USTD, 1860)
Leather	1.3E+09	g/y(USTD, 1860)
Leather boots & shoes	3.9E+08	g/y (estimated from USTD (1860))
Mules	7.2E+08	g/y (estimated from USTD (1860))
Pork	1.8E+10	g/y (estimated from USTD (1860))
Soap	3.1E+09	g/y (USTD, 1860)
Tallow	6.0E+10	g/y (USTD, 1860)
Wax	1.6E+08	g/y (USTD, 1860)
Wool	5.4E+08	g/y (USTD, 1860)
1860 total =	8.1E+10	g/y

1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	3.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1860 energy in exports =	5.1E+14	J/y

50 FISHERIES PRODUCTS

Fish, dried or smoked	1.1E+10	g/y (estimated from USTD (1860))
pickled	4.1E+09	g/y (estimated from USTD (1860))
1860 total =	1.5E+10	g/y

1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	3.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1860 energy in exports =	3.1E+14	J/y

51 WHALE PRODUCTS:

Spermaceti candles	7.2E+07	g/y (USTD, 1860)
Oil, spermaceti	4.4E+09	g/y (estimated from USTD (1860))
whale and other fish	3.3E+09	g/y (estimated from USTD (1860))
Whalebone	4.8E+08	g/y (USTD, 1860)
1860 total =	8.2E+09	g/y

1860 energy in exports = (export) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g

dry-wt/wet-wt =	3.0E-01	g dry/g wet (estimated from Crampton & Harris (1969))
energy/g =	2.1E+04	J/g (estimated from Odum (1969))
1860 energy in exports =	5.1E+13	J/y

52 IRON EXPORT

Iron & manufactures of iron

bar 4.7E+08 g/y (USTD, 1860)

castings 3.1E+09 g/y (USTD, 1860)

nails 2.3E+09 g/y (USTD, 1860)

pig 4.1E+08 g/y (USTD, 1860)

manufactures of iron 2.0E+09 g/y (estimated from USTD (1860))

total export = 8.3E+09 g/y

53 BULLION & COIN Gold and silver = 4.1E+07 g/y (estimated from USTD (1860))

54 HUMAN SERVICES NOT ACCOUNTED FOR IN TRANSFORMITIES USED ABOVE

embodied in exports (1860) = 3.3E+08 $/y (USTD, 1860)

services accounted for in transformities of products in terms above

= 1.1E+08 $/y

services embodied in imports that are not accounted for above

= 2.2E+08 $/y

The emergy-money ratio is that calculated for the U.S. in this evaluation.

55 HUMAN SERVICES IN EXPORTS TO THE CONFEDERATE STATES (CSA)

Services in exports to CSA = 2.6E+08 $/y (Fishlow, 1964)

APPENDIX I
CALCULATIONS IN SUPPORT OF TABLE 3-26, CHANGES IN THE EMERGY EVALUATION OF THE UNION STATES FROM 1862 THROUGH 1865.

Unless otherwise stated, the energy calculations and transformities used are from the corresponding terms in Table 3-23 and Appendix H.

term:			
11	1862 PLANT LEAF, FIBER, & PRODUCTS		
	Hay	1.9E+13	g/y (USDA, 1863)
	Tobacco	6.2E+10	g/y (USDA, 1863)
	1862 energy of total production =	2.8E+17	J/y
	1863 PLANT LEAF, FIBER, & PRODUCTS		
	Hay	1.7E+13	g/y (USDA, 1864)
	Tobacco	7.4E+10	g/y(USDA, 1864)
	1863 energy of total production =	2.4E+17	J/y
	1864 PLANT LEAF, FIBER, & PRODUCTS		
	Hay	1.6E+13	g/y (USDA, 1865)
	Tobacco	9.0E+10	g/y (USDA, 1865)
	1864 energy of total production =	2.4E+17	J/y
	1865 PLANT LEAF, FIBER, & PRODUCTS		
	Hay	2.1E+13	g/y (USDA, 1866)
	Tobacco	8.3E+10	g/y (USDA, 1866)
	1865 energy of total production =	3.1E+17	J/y
12	1862 BREADSTUFFS & GRAINS		
	Barley	1.7E+11	g/y (estimated from USDA (1863))
	Buckwheat	2.6E+11	g/y (estimated from USDA (1863))
	Indian corn	7.3E+12	g/y (estimated from USDA (1863))
	Oats	2.3E+12	g/y (estimated from USDA (1863))
	Rye	2.8E+11	g/y (estimated from USDA (1863))
	Wheat	2.4E+12	g/y (estimated from USDA (1863))
	1862 total energy of production =	1.9E+17	J/y
	1863 BREADSTUFFS & GRAINS		
	Barley	1.7E+11	g/y (estimated from USDA (1864))
	Buckwheat	2.1E+11	g/y (estimated from USDA (1864))
	Indian corn	5.4E+12	g/y (estimated from USDA (1864))
	Oats	2.3E+12	g/y (estimated from USDA(1864))
	Rye	2.7E+11	g/y (estimated from USDA (1864))
	Wheat	2.4E+12	g/y (estimated from USDA (1864))
	1863 total energy of production =	1.6E+17	J/y
	1864 BREADSTUFFS & GRAINS		
	Barley	1.5E+11	g/y (estimated from USDA(1865))
	Buckwheat	2.5E+11	g/y (estimated from USDA (1865))
	Indian corn	7.2E+12	g/y (estimated from USDA (1865))
	Oats	2.4E+12	g/y (estimated from USDA (1865))
	Rye	2.7E+11	g/y (estimated from USDA (1865))
	Wheat	1.6E+08	g/y (estimated from USDA (1865))
	1864 total energy of production =	1.6E+17	J/y

1865 BREADSTUFFS & GRAINS
Barley 1.6E+11 g/y (estimated from USDA (1866))
Buckwheat 2.5E+11 g/y (estimated from USDA (1866))
Indian corn 9.6E+12 g/y (estimated from USDA (1866))
Oats 3.1E+12 g/y (estimated from USDA (1866))
Rye 2.7E+11 g/y (estimated from USDA(1866))
Wheat 2.0E+12 g/y (estimated from USDA (1866))
1865 total energy of production = 2.3E+17 J/y
The transformity used is that for basic primary production.

12a The transformity used is that calculated for corn in the evaluation of U.S. agriculture in 1860.

23 CRUDE PETROLEUM:
1862 extraction = 1.9E+16 J/y (from Rothwell (1892))
1863 extraction = 1.6E+16 J/y (from Rothwell (1892))
1864 extraction = 1.3E+16 J/y (from Rothwell (1892))
1865 extraction = 1.5E+16 J/y (from Rothwell (1892))

30 SILVER
1862 extraction = 1.1E+08 g/y (Rothwell, 1892)
1863 extraction = 2.0E+08 g/y (Rothwell, 1892)
1864 extraction = 2.6E+08 g/y (Rothwell, 1892)
1865 extraction = 2.7E+08 g/y (Rothwell, 1892)
The transformity used is an estimate of the emergy value of unrefined silver.

30a These calculations use the Sundberg et al. (In Press) transformity for refined silver.

34 RAW COTTON IMPORT
1862 import = 1.9E+14 J/y (from USTD (1864))
1863 import = 2.2E+14 J/y (from USTD (1865a))
1864 import = 1.7E+14 J/y (from USTD (1865b))
1865 import = n.a. J/y (from USTD (1866))

40 COIN, SILVER
1862 silver coin import = 4.1E+07 g/y (estimated from USTD (1864))
1863 silver coin import = 7.2E+07 g/y (estimated from USTD (1865a))
1864 silver coin import = 3.3E+07 g/y (estimated from USTD (1865b))
1865 silver coin import = 1.3E+07 g/y (estimated from USTD (1866))

41 COIN, GOLD
1862 gold coin import = 1.3E+07 g/y (estimated from USTD (1864))
1863 gold coin import = 3.8E+06 g/y (estimated from USTD (1865a))
1864 gold coin import = 9.1E+06 g/y (estimated from USTD (1865b))
1865 gold coin import = 5.4E+06 g/y (estimated from USTD (1866))

42 TOTAL HUMAN SERVICES EMBODIED IN FOREIGN IMPORTS
1862 Services in imports = 2.2E+08 $/y (USTD, 1864)
1863 Services in imports = 2.7E+08 $/y (USTD, 1865a)
1864 Services in imports = 3.6E+08 $/y (USTD, 1865b)
1865 Services in imports = 2.7E+08 $/y (USTD, 1866)

43 TOTAL HUMAN SERVICES EMBODIED IN IMPORTS FROM CONFEDERATE STATES
Imports from the Confederate states are difficult to determine.

44 NET IMMIGRATION
1862 immigration = 1.1E+05 people/y (USDC, 1975)
1863 immigration = 2.0E+05 people/y (USDC, 1975)
1864 immigration = 2.2E+05 people/y (USDC, 1975)
1865 immigration = 2.9E+05 people/y (USDC, 1975)

48 COTTON
1862 export = 6.4E+13 g/y (USTD, 1864)
1863 export = 6.9E+13 g/y (USTD, 1865a)
1864 export = 7.9E+13 g/y (USTD, 1865b)
1865 export = 5.9E+13 g/y (USTD, 1866)

53 GOLD & SILVER COIN & BULLION

1862 export = 2.7E+07 g/y (estimated from USTD (1864))
1863 export = 6.7E+07 g/y (estimated from USTD (1865a))
1864 export = 1.3E+08 g/y (estimated from USTD (1865b))
1865 export = 5.3E+07 g/y (estimated from USTD (1866))

54 TOTAL HUMAN SERVICES EMBODIED IN FOREIGN EXPORTS

Services in exports (1860) = 1.4E+08 $/y (USTD, 1860)
Services in exports (1862) = 2.1E+08 $/y (USTD, 1864)
Services in exports (1863) = 3.1E+08 $/y (USTD, 1865a)
Services in exports (1864) = 3.2E+08 $/y (USTD, 1865b)
Services in exports (1865) = 3.1E+08 $/y (USTD, 1866)

55 TOTAL HUMAN SERVICES EMBODIED IN EXPORTS TO CONFEDERATE STATES

Exports to the Confederate states are difficult to determine.

APPENDIX J

CALCULATIONS IN SUPPORT OF TABLE 3-27, EMERGY OF THE REQUIREMENTS, FLOWS, AND DESTRUCTION STORAGES DURING THE UNITED STATES CIVIL WAR, 1861-1865.

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term:

1 LEAD
Lead issued alone = 4.10E+10 g (ORUCA iii-v)
Lead issued in small arms cartridges = 3.71E+10 g (estimated from ORUCA (iii-v), assuming 36.3 g lead/cartridge)
Total lead issue = 7.81E+10 g

2 ARTILLERY PROJECTILES
Artillery projectiles = 5.84E+09 g (ORUCA iii-v)
Fixed artillery ammo. = 5.03E+10 g (estimated from ORUCA (iii-v), assuming 40 lb /round)
Total artillery projectiles = 5.62E+10 g

3 GUN POWDER
Gun powder issued alone = 1.20E+10 g (ORUCA iii-v)
Gun powder issued in cartridges = 3.97E+09 g (estimated from ORUCA (iii-v), assuming 3.89 g powder/cartridge)
Cannon primer & fuse = 4.35E+08 g (estimated from ORUCA (iii-v), assuming 30 g powder/piece)
Total gun powder issue = 1.64E+10 g

4 NITER Union issue = 4.10E+10 g (ORUCA iii-v)

5 HORSES & MULES labor or power = 1.19E+06 head-y (calculated from ORUCA iii-v)

6 HORSES & MULES animals killed or worn out = 1.71E+05 head (estimated from ORUCA iii-v)
This transformity assumes a 3 y maturation period for horses and is 3 times the transformity in term 5.

7 WEAPONS, Union Army issue
Small arms = 4.02E+06 pieces (ORUCA iii-v)
estimated wt. per piece = 4.18E+03 g (assumed)
wt. of small arms issue = 1.68E+10 g
Cannon = 7.89E+03 pieces (ORUCA iii-v)
estimated wt. per piece = 6.59E+05 g (assumed)
wt. of cannon issue = 5.20E+09 g
total wt. of weapons = 2.20E+10 g

8 LABOR OF UNION TROOPS = 4.67E+06 man-y (Livermore, 1900)
The transformity used is the annual per capita emergy use (I19) from the Federal States Evaluation

9 DEATHS OF UNION TROOPS
died of wounds = 1.10E+05 persons (Livermore, 1900)
died of disease = 2.49E+05 persons (Livermore, 1900)
died in prison = 3.02E+04 persons (as accepted by McPherson (1992))
less the deaths occurring in the absence of war ((1870 mortality rate for 15 - 39 year olds) * (labor of troops))
deaths that would have occurred = 5.60E+04 persons (mortality rate = 0.012 deaths/person-year (USCO, 1874))
Deaths attributable to war = 3.34E+05 persons
The transformity used is 16 times the annual emergy use per person from the Federal States evaluation. This transformity assumes 16 years are required for human maturation.

10 DISABLING INJURIES TO UNION TROOPS

Total number discharges due to wounds = 3.56E+04 persons (calculated from "died of wounds" using the French World War I statistic suggested by Beringer et al. (1986) of the number discharged for wounds as 32.3% of number killed)
This transformity is assumed as 30% of the transformity used for Union war deaths.

11 PRISONERS OF WAR, Union troops in CSA war prisons

total number ever imprisoned = 1.95E+05 persons (the number accepted by McPherson (1992))
average time of imprisonment = 7.50E-01 y (assumed from the pattern of prisoner exchanges)
labor lost in prisons = 1.46E+05 person-y

12 UNION NAVAL LABOR

maximum size of USN = 1.33E+05 persons (Davis, 1991)
duration of enlistment = 3.00E+00 years (assumed)
labor in USN = 3.98E+05 person/y

13 UNION NAVAL CASUALTIES

died of wounds = 1.80E+03 persons (Fox, 1889)
died of disease = 3.00E+03 persons (Fox, 1889)
less the deaths occurring in the absence of war ((1870 mortality rate for 15 - 39 year olds) * (labor of troops))
deaths that would have occurred = 4.77E+03 persons (mortality rate = 0.012 deaths/person-y (USCO, 1874))
Deaths attributable to war = 3.21E+01 persons
Transformity is that used for the Army above.

14 FUEL

J used per gram of vessel per year = 9.47E+05 J/y (estimated from ORUCA (iii-v, p. 289) data)
estimated gram-vessel-years of service in war = 8.18E+11 g-vessel-y (estimated for total tonnage of Union vessels (term 15) for 2 years)

estimated total fuel use = 7.75E+17 J
The transformity used is that for coal

15 WEAPONS

Estimated wt. of naval guns = 6.47E+09 g (estimated from Soley (1883) and Long (1971) assuming 6000 lbs./gun)

16 UNION NAVAL & QUARTERMASTER VESSELS

Iron clads = 7.80E+10 g (Soley, 1883)
iron in iron clads = 3.90E+10 g (estimated as 50% of vessels' weight as iron)
wood in iron clads = 3.90E+10 g (estimated as 50% of vessels' weight as wood)

Unarmored vessels = 1.27E+11 g (Soley, 1883)
iron in vessels = 2.54E+10 g (estimated as 20% of vessels' weight as iron)
wood in vessels = 1.02E+11 g (estimated as 80% of vessels' weight as wood)

QUARTERMASTER CORPS

Streamers & tugs = 1.67E+11 g(ORUCA data for 1864/1865 fiscal year)
iron in vessels = 3.34E+10 g (estimated as 20% of vessels' weight as iron)
wood in vessels = 1.34E+11 g (estimated as 80% of vessels' weight as wood)

Sail-vessels & barges = 3.69E+10 g (ORUCA data for 1864/1865 fiscal year)
iron in vessels = 1.84E+09 g (estimated as 5% of vessels' weight as iron)
wood in vessels = 3.50E+10 g (estimated as 95% of vessels' weight as wood)

TOTALS:

Total tonnage of vessels above = 4.09E+11 g
service in construction = 2.47E-04 $/g (estimated from the construction cost of the "Alabama")

1860 emergy-money ratio = 7.36E+13 sej/$ (1860 USA evaluation)
service emergy in vessels = 7.44E+21 sej

total iron = 1.39E+11 g
iron transformity = 1.05E+10 sej
emergy of iron = 1.46E+21 sej

total wood = 3.09E+11 g
wood transformity = 3.50E+04 sej
emergy of wood = 1.08E+16 sej

Total emergy of vessels = (emergy of services) + (emergy of iron) + (emergy of wood)
Total emergy of vessels = 8.9E+21 sej

17 DESTROYED & CAPTURED MERCHANT & WHALING VESSELS
Value of vessels & cargoes = 1.8E+07 (Scharf, 1887)
1870 emergy-money ratio = 3.02E+13 sej/$ (USA 1870 evaluation)
emergy of vessels & cargoes = 5.41E+20 sej

estimated tonnage of vessels = 7.80E+10 g (Estimated from Scharf's (1887) statistics on destroyed vessels)
iron in vessels = 3.90E+09 g (estimated as 5% of vessels' weight as iron)
iron transformity = 1.05E+10 sej
emergy of iron = 4.10E+19 sej

wood in vessels = 7.41E+10 g (estimated as 95% of vessels' weight as wood)
wood transformity = 3.50E+04 sej
emergy of wood = 2.59E+15 sej

Total emergy of vessels = (emergy of services) + (emergy of iron) + (emergy of wood)
Total emergy of vessels = 5.8E+20 sej

18 UNION CIVIL SERVANTS
Civilians in civil service = 100,000 persons (Touchstone, 1993)
estimated service per person = 3.5 y (assumed)
Labor in civil service = 3.50E+05 person-y

19 OTHER: UNACCOUNTED FOR HUMAN SERVICES IN UNION WAR EFFORT
Union dollar cost for military ops. = 2.12E+09 1860 dollars (direct cost from Goldin and Lewis (1975))
1860 Union states emergy-money ratio = 7.47E+13 sej/$ (Union states evaluation)
Emergy value of this dollar cost = 1.59E+23 sej (dollar cost * emergy-money ratio)
Total emergy in terms 1,2,3,4,6,7,8,12,14,15,&16 = 8.90E+21 sej
Difference between the two items above = 1.50E+23 sej

20 CONFEDERATE LEAD total issue = 4.54E+09 g (Robertson, 1993)

21 CONFEDERATE ARTILLERY PROJECTILES = 1.97E+10 g (estimated as 35% of Union value)

22 CONFEDERATE GUN POWDER
Gun powder issued alone = 1.17E+08 g (estimated)
Gun powder issued in cartridges = 5.84E+08 g (estimated from Thomas (1993))
Cannon primer & fuse = 14507682*30 g (estimated from ORUCA (iii-v), assuming 30 g powder/piece)
Total gun powder issue = 7.00E+08 g

23 CONFEDERATE HORSES & MULES = 7.14E+05 head-y (estimated as 60% of Union horse use)

24 HORSES & MULES, animals killed or worn out = 1.20E+05 head (estimated as 70% of Union horse losses)
This transformity assumes a 3 y maturation period for horses and is 3 times the transformity in term 5.

25 WEAPONS, CONFEDERATE Army issue
Small arms = 5.95E+05 pieces (estimated from Huey and Madaus (1993) and Pritchard (1993a, 1993d))
estimated weight per piece = 4.18E+03 g (assumed)
weight of small arms issue = 2.48E+09 g
Cannon = 4.20E+03 pieces (estimated from Huey (1993) and Pritchard (1993b; 1993c))
estimated weight per piece = 4.40E+05 g (assumed)
weight of cannon issue = 1.85E+09 g
total weight of weapons = 4.33E+09 g

26 LABOR OF CONFEDERATE TROOPS = 3.25E+06 man-y (Livermore, 1900)
The transformity used is the annual per capita emergy use (I19) from the Confederate states evaluation .

27 DEATHS OF CONFEDERATE TROOPS
died of wounds = 9.40E+04 persons (Livermore, 1900)
died of disease = 1.64E+05 persons (Livermore, 1900)
died in prison = 2.60E+04 persons (as accepted by McPherson (1992))
less the deaths occurring in the absence of war ((1870 mortality rate for 15 - 39 year olds) * (labor of troops))
deaths that would have occurred = 3.90E+04 persons (mortality rate = 0.012 deaths/person-y (USCO, 1874))
Deaths attributable to war = 2.45E+05 persons
The transformity used is 16 times the annual emergy use per person from the Federal States evaluation. This transformity assumes 16 years are required for human maturation.

28 DISABLING INJURIES TO CONFEDERATE TROOPS
total number discharges due to wounds = 3.04E+04 persons (calculated from "died of wounds" using the French World War I statistic suggested by Beringer et al. (1986) of the number discharged for wounds as 32.3% of number killed)
This transformity is assumed to be 30% of the transformity used for Union war deaths.

29 PRISONERS OF WAR, CONFEDERATE TROOPS IN USA WAR PRISONS
total number ever imprisoned = 2.15E+05 persons (the number accepted by McPherson (1992))
average time of imprisonment = 7.50E-01 y (assumed from the pattern of prisoner exchanges)
labor lost in prisons = 1.61E+05 person-y

30 CONFEDERATE NAVAL LABOR
maximum size of CSN = 4.00E+03 persons (approximated from Scharf (1887))
duration of enlistment = 3.00E+00 years (assumed)
labor in USN = 1.20E+04 person/y

31 CONFEDERATE NAVAL CASUALTIES
Died of wounds = 5.44E+01 persons (estimated from the probability of death in the USN)
died of disease = 9.05E+01 persons (estimated from the probability of death in the USN)
less the deaths occurring in the absence of war ((1870 mortality rate for 15 - 39 year olds) * (labor of troops))
deaths that would have occurred = 1.44E+02 persons (mortality rate = 0.012 deaths / person-y (USCO, 1874))
Deaths attributable to war = 9.67E-01 persons
Transformity is that used for the Army above.

32 CONFEDERATE NAVAL FUEL
J used per gram of vessel per year = 9.47E+05 J/y (estimated from ORUCA (iii-v, p. 289) data for Union vessels)
estimated gram-vessel-years of service in war = 3.49E+10 g-vessel-y (estimated for total tonnage of Union vessels (term 15) for 2 years)
estimated total fuel use = 3.31E+16 J
The transformity used is that for coal

33 CONFEDERATE NAVAL WEAPONS
Estimated wt. of naval guns = 3.30E+09 g (estimated from Tucker (1993a; 1993b; 1993c) assuming 6000 lbs./gun)

34 CONFEDERATE NAVAL VESSELS
Iron Clads, completed & uncompleted = 3.43E+10 g (estimated from Scharf (1887))
iron in iron clads = 1.71E+10 g (estimated as 50% of vessels' weight as iron)
wood in iron clads = 1.71E+10 g (estimated as 50% of vessels' weight as wood)

Unarmored vessels = 6.59E+10 g (estimated from Scharf (1887))
iron in vessels = 1.32E+10 g (estimated as 20% of vessels' weight as iron)
wood in vessels = 5.27E+10 g (estimated as 80% of vessels' weight as wood)

TOTALS:
Total tonnage of vessels above = 6.99E+10 g
service in construction = 2.47E-04 $/g (estimated from the construction cost of the "Alabama")
1860 emergy-money ratio = 7.36E+13 sej/$ (1860 USA evaluation)
service emergy in vessels = 7.44E+21 sej

total iron = 3.03E+10 g
iron transformity = 1.05E+10 sej
emergy of iron = 3.19E+20 sej

total wood = 6.99E+10 g
wood transformity = 3.50E+04 sej
emergy of wood = 2.45E+15 sej

Total emergy of vessels = (emergy of services) + (emergy of iron) + (emergy of wood)
Total emergy of vessels = 8.9E+21 sej

35 DESTROYED & CAPTURED BLOCKADE RUNNING VESSELS
estimated tonnage of vessels = 1.94E+11 g (Estimated from Wise's (1988) statistics on destroyed and captured vessels)
iron in vessels = 3.89E+10 g (estimated as 5% of vessels' weight as iron)
iron transformity = 1.05E+10 sej
emergy of iron = 4.08E+20 sej

wood in vessels = 6.24E+10 g (estimated as 95% of vessels' weight as wood)
wood transformity = 3.50E+04 sej
emergy of wood = 2.18E+15 sej

service in construction =2.47E-04$/g (estimated from the construction cost of the "Alabama")
1860 emergy-money ratio = 7.36E+13 sej/$ (1860 USA evaluation)
service emergy in vessels = 7.44E+21 sej

Total emergy of vessels = (emergy of services) + (emergy of iron) + (emergy of wood)
Total emergy of vessels = 7.8E+21 sej

36 CONFEDERATE CIVIL SERVANTS
Civilians in civil service = 70,000 persons (Touchstone, 1993)
estimated service per person = 3.5 y (assumed)
Labor in civil service = 2.45E+05 person-y

37 OTHER: UNACCOUNTED FOR HUMAN SERVICES
CSA dollar cost for military ops. = 1.01E+09 1860 dollars (direct cost from Goldin and Lewis (1975))
1860 Confederate states emergy-money ratio = 1.04E+14 sej/$ (Confederate states evaluation)
Emergy value of this dollar cost = 1.05E+23 sej (dollar cost * emergy-moneyratio)
Total emergy in terms 20, 21, 22, 24, 25, 26, 30, 32, 33, & 34 = 8.90E+21 sej
Difference between the two items above = 9.58E+22 sej

38 DAMAGES TO CONFEDERATE RESOURCES (STORAGES): ALL PROPERTY
Dollar value of wealth loss (corrected for inflation) = 1.23E+09 $ (Sellers, 1927)

39 LOSS OF CONFEDERATE LIVESTOCK
Estimated weight of CSA livestock, 1860 = 4.08E+12 g (estimated from USCO (1864) assuming 300 lbs/head)
1860 energy in livestock = (weight) g * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 3.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 2.1E+04 J/g (estimated from Odum (1969))
1860 energy in livestock = 2.6E+16 J
Percentage of CSA livestock lost = 40% (Sellers, 1927)
Energy of CSA livestock loss = 1.02E+16 J

40 DESTRUCTION OF CONFEDERATE FARM EQUIPMENT & FARM IMPROVEMENTS
Percentage of CSA farm equipment destroyed = 55% (Sellers, 1927)
1860 value of CSA farm improvements & machinery = 8.40E+07 (USCO, 1864)
Dollar value of farm improvements lost = 4.62E+07 $
Transformity used is that calculated to exclude labor in term 43

41 DESTRUCTION OF OTHER CONFEDERATE PROPERTY (Buildings, Railroads, Factories, etc.)
1860 value of CSA livestock = 8.40E+07 (USCO, 1864)
Percentage of CSA livestock lost = 40% (Sellers, 1927)
Dollar value of livestock loss = 3.36E+07 $ (value * % loss)
Dollar value of farm improvements lost = 4.62E+07 $
Dollar value of all property lost = 1.23E+09 $ (Sellers, 1927)
Dollar value of property loss excluding agriculture = 1.20E+09 $
Transformity used is that calculated to exclude labor in term 43

42 LOSS OF OTHER STORAGES IN THE CONFEDERACY
Increased civilian deaths = unknown

43 EVALUATION OF A ROLLING MILL, OFFICE BUILDINGS, AND QUARTERS, constructed in 1864 (excluding the cost and emergy of the mill's machinery) to determine an emergy per dollar conversion for equipment and improvements. Unless otherwise specified, all data are from ORUCA (iii-v, pp. 961-962)

LABOR COST = 1.23E+05 $
labor wage rate = 2.00E+00 $/person-day (weighted for skilled and non-skilled labor from USDC (1975))
Labor use = 6.17E+04 person-day
Emergy conversion for labor = 1.46E+13 sej/person-day (from USA 1860 evaluation allocating 18 hours/day for labor & labor related activities)
Emergy in labor = 9.01E+17 sej

WOOD = 7.21E+08 g
Energy in wood = (wood) g/y * (dry-wt/wet-wt) g/g * (energy/g) J/g
dry-wt/wet-wt = 9.0E-01 g dry/g wet (estimated from Crampton and Harris (1969))
energy/g = 1.7E+04 J/g (estimated from Odum (1969))
Energy in wood = 1.1E+13 J/y
Transformity of wood = 3.50E+04 sej/J
Emergy in wood = 3.86E+17 sej

IRON = 8.14E+06 g
Transformity of iron = 1.1E+10 sej/J
Emergy in iron = 8.56E+16 sej

bricks = 2.20E+08 g
Transformity of bricks = 1.70E+09 sej/g (using transformity for clay)
Emergy in bricks = 3.74E+17 sej

LIME = 3.96E+07 g
Transformity of lime = 1.00E+09 sej/g
Emergy in lime = 3.96E+16 sej

Total emergy in construction = 1.79E+18 sej
Total dollar cost of construction = 1.47E+05 $
Estimated emergy per dollar of improvements = 1.21E+13 sej/$ (emergy in construction/dollar cost of construction)
Estimated emergy per dollar of improvements excluding emergy in labor =
3.73E+13 sej/$ (emergy conversion - emergy in labor)

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BIOGRAPHICAL SKETCH

Robert D. Woithe, the son of Robert A. and Susan P. Woithe of Palm Island, Florida, was born in Morristown, New Jersey, on January 22, 1966. Bob was raised in Basking Ridge, New Jersey, and graduated from Ridge High School in June 1984. In September 1984, he entered Middlebury College in Middlebury, Vermont. There he was initiated into Alpha Mu of the Chi Psi Fraternity in April 1985. Bob graduated from Middlebury in May 1988 with an A.B. in biology and a concentration in American history. In June of that year, he began postbaccalaureate study in the University of Florida, College of Agriculture. He entered the systems ecology, energy analysis and wetlands master's degree program of the University of Florida, Department of Environmental Engineering Sciences in August 1989. From 1990 through 1992, Bob was a graduate research assistant at the University of Florida's Center for Wetlands and Water Resources, supported by a grant from The Cousteau Society to study the *Exxon Valdez* oil spill and oil spill prevention. He graduated in May 1992 with a Master of Science and a Graduate Certification in Wetlands, and began doctoral studies in the Department of Environmental Engineering Sciences. Bob's research was supported through a graduate assistantship under H T. Odum, and research grants to study the impacts of Hurricane Andrew and comparisons of Asian and American cities. While in Florida, Bob served as President, Vice President, and Treasurer of the Alpha Mu Delta of Chi Psi Alumni Corporation at Rollins College, Winter Park, Florida, Trustee and Sesquicentennial Chairman of the Alpha Mu of Chi Psi Alumni Corporation, Middlebury, Vermont, and a Program for Self Development Instructor for the Chi Psi Educational Trust, Ann Arbor, Michigan.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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