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AN ENVIRONMENTAL VALUE ENGINEERING (EVE) EMERGY ANALYSIS RUBRIC TO COMPARE HIGH-SPEED PASSENGER RAIL AND INTERSTATE PASSENGER CAR TRANSPORTATION ALTERNATIVES THROUGH A FIXED DISTANCE

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ABSTRACT

An Environmental Value Engineering (EVE) analysis was used to conduct an environmental life cycle assessment of transportation alternatives consisting of high-speed passenger rail and interstate passenger car transportation. This analysis was formulated on the EMERGY inputs of environment, fuel energy, goods, and services (labor). EMERGY input tables were calculated based on subsystem inputs for each mode of transportation. Areas of commonality were identified for analysis exclusion while aspects that showed differentiation were included as viable inputs into the calculation of the total EMERGY for each system. The summation of inputs resulted in an overall EMERGY calculation of the alternatives. Subsequently, the system with the lowest aggregate EMERGY per passenger mile was identified as the one having the least impact on the environment while meeting the need of transporting people. In an effort to further determine if a significant difference existed between these transportation alternatives, a multivariate analysis of variance (MANOVA) was conducted utilizing aggregate EMERGY values of environment, fuel energy, goods, and services.

The following results are specific to this analysis such that the conclusions cannot be extrapolated without a specific evaluation of those conditions. An analysis of the EMERGY per passenger mile results determined that the interstate passenger car alternative met the need of transporting people while having the least impact on the environment. A review of the MANOVA results indicated that there was not a significant difference between the transportation alternatives impact on the environment.

Additional environmental variables such as vehicle and locomotive material composition analysis, greenhouse gas emission, ecological footprint and ecological economics were identified as areas of consideration for future research. The variables of interest could be included in the EVE analysis and result in a modified EVE and be defined as a composite environmental return on investment (CE-ROI).

PREFACE

I want to acknowledge my acceptance of Jesus Christ as my Lord and Savior. To my late parents, I dedicate this accomplishment to you. To my family and my associates, I simply say thanks so much for your patience, support, and understanding in all aspects of my life in which you contribute. I want to personally thank Mr. Clarence M. Ball, Jr. for being a friend; may God continue to bless you and your family.

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CHAPTER 1

INTRODUCTION

As a result of the limited number of natural resources, it is inherent that adequate research is conducted to validate sustainable design and construction alternatives. Environmental sustainability can be viewed from a dynamic and value based approach; as such, the measurement of its values changes with time (Whitford & Wong, 2009). A sustainable approach is one that meets the need of the intended purpose while reducing the environmental impact that results from the finished product. Society is at risk as it relates to sustainability from two perspectives; a reduction in the availability of nonrenewable resources and the negative impact on the quality of our renewable resources (Kitzes et al., 2008).

"An environmental value engineering assessment compares multiple alternatives over a life cycle consisting of 10 phases: natural resource formation, natural resource exploration and extraction, material production, design, component production, construction, use, demolition, natural resource recycling, and disposal" (Roudebush, 1996, p. 1). This analysis was formulated on the EMERGY inputs of environment, fuel energy, goods, and services (labor). Scienceman (1987) coined the term EMERGY when he documented the nomenclature of energy and EMERGY (as cited in Roudebush, 1996). Odum and Arding (1991) defined EMERGY as a scientific–based measure of wealth that puts raw materials, commodities, goods, and services on a common basis as the energy of one type required to generate that item. Researchers continue to review and analyze Odum's original work on EMERGY. Pereira and Ortega (2010) indicated that the global EMERGY baseline calculation consists of solar energy, tidal energy, and deep earth heat. Additionally, they suggested two alternatives when using EMERGY values; one can either multiply older values by 1.68 or multiply newer values by 0.60. This conversion is recommended due to a lack of clarification of a global EMERGY baseline of $15.83\ x\ 10^{\ 24}$ seJ/yr or $9.44\ x\ 10^{\ 24}$ seJ/yr.

Although various methods of project delivery exist, there has not been a concerted effort to consistently integrate a system of analysis of environmental impacts to determine the feasibility of a specific design or construction alternative. Pereira and Ortega (2011) indicated that no one single model is capable of providing a comprehensive environmental analysis of a sustainable issue. With the increased access to knowledge that substantiates concerns such as the global economic downturn, urban sprawl, and the impact of greenhouse gas emissions, it is prudent that large projects are viewed from a comprehensive aspect of viability. Historically, owners are very concerned about cost, schedule and quality. It is very difficult to achieve all three without some type of trade off. If the schedule is accelerated, cost usually goes up. If quality is a priority, cost and schedule normally increase. Based upon this observation, these items are in some aspects inversely proportional. A new paradigm that shifts the owners concerns is the inclusion of sustainability as one of the control variables (Baker, 2009).

The current state of limited natural resources, economic downturn, and global warming are strategic areas of concern for future generations. Greenhouse gas emissions in the United States have increased approximately 15% since 1990 (U.S. Environmental Protection Agency [EPA], 2013a). Global warming is increasing as a result of the atmospheric impact of greenhouse gases. Greenhouse gases are raising the earth's temperature by trapping heat within the lower atmosphere (Montzka, Dlugokencky, & Butler, 2011). An additional item of consideration in the development of transportation alternatives is the impact that urban sprawl is having on the limited financial resources. Due to a decrease in population density in urban areas, service providers are challenged to gain a positive economy of scale by extending viable transportation alternatives, water, sewer and electricity. Knutti (2008) argued that although various climate change models exist, more emphasis should be placed on understanding the data that the models generate.

Transit funding in the United States has experienced a transition of funding sources over the last 50 years. The funding is shifting from the private sector to federal, state, and local governments (Hess & Lombardi, 2005). The Pacific Railway Act of 1862 was cited as being among the 100 documents that shaped America (U.S. News & World Report, 2013). The U. S. government passed this act to facilitate the construction of the railroad and telegraph line. In return for its assistance, it would receive utilization rights of the line. Ultimately, the government authorized the construction of four transcontinental railroads which resulted in the allocation of 174 million acres of public land to be used for right-of-way.

Weingroff (2011) indicated that the government commissioned a report in the mid-1950s that substantiated the design and construction of the modern day interstate system. The report acknowledged that although other means of transportation existed, their focus was on improving the roadway. The substantiating factors in the decision to build them focused on population growth, increased number of vehicles, associated accidents, national security and the opportunity to put people to work. Ultimately, the decision was made to build them based on the previous list of items while the funding mechanism to pay for them followed. The project has proven its value to the transportation network of this country and continues to stimulate growth and development and validates the foresight of President Eisenhower.

The Federal Railroad Administration (FRA) has proposed a series of transportation improvements consisting of high-speed and intercity passenger rail connections to enhance the movement of people. If approved and implemented, this approach will rival the design and construction of President Eisenhower's interstate system and incorporate the ability to move multiple passengers from point to point at speeds in excess of 125 miles per hour and improve economic development. Peterman, Frittelli, and Mallett (2012) prepared a report for Congress that indicated that passenger rail is proven technology that has been most successfully implemented in Japan, mainly because of the geographical layout and relative population density. Additionally, they noted some impediments to the success of passenger rail implementation in the United States. These challenges include items such as high cost relative to the small percentage of passengers that would use it instead of traveling by air or interstate highway.

The application such as environmental value engineering could result in a more sustainable project deliverable. This in essence could change the approach to the entire process from the initial master plan to final commissioning of major project alternatives. The emphasis of a sustainable analysis application such as environmental value engineering (EVE) could enhance the focus of research concentrations for future material, energy and transportation sources. An example is that one would tend to shift preferences to the options identified through a sustainable analysis as having the greatest societal benefits at the least environmental impact. At this point, there may not be enough data to support some of the proposed green methods of design, construction, or energy deliverables when viewed from an EVE perspective.

The Problem Statement

The globalization of our economy has increased the frequency in which people travel domestically and internationally. The need to satisfy this increased travel demand has had a significant impact on the quantity and quality of resources remaining. As a result of limited resources, it is prudent to determine the most sustainable way to satisfy the increased travel requirements. A sustainably designed and constructed built environment project will ensure that adequate resources remain in an effort to meet the needs of future societies. Kitzes et al. (2008) stated that a decrease in the availability of nonrenewable natural resources and the fact that our renewable resources are impacted by a reduction in quality are two primary risks facing the sustainability of our society. An EVE EMERGY analysis was used to compare high-speed passenger rail and interstate passenger car transportation to determine which has the least impact on the environment while meeting the need of transporting people. Therefore, the problem of this research was to determine an effective methodology to evaluate the environmental impact of high-speed passenger rail and interstate passenger car transportation through a fixed distance to determine the alternative with the least impact on the environment.

Research Questions

1. What is an effective methodology for evaluating the environmental impact of high-speed passenger rail and interstate passenger car transportation alternatives?
2. Which transportation alternative had the least impact on the environment while meeting the need of transporting people?

Hypothesis

H_0: The null hypothesis stated that there was no difference in terms of environmental impacts between the construction of high-speed passenger rail and interstate passenger car transportation systems.

H_a: The alternative hypothesis stated that there was a difference in terms of environmental impacts between the construction of high-speed passenger rail and interstate passenger car transportation systems.

EVE is an analysis method that was used to compare rail and interstate transportation alternatives in the built environment over a life cycle consisting of 10 phases. The EVE analysis resulted in the recommendation to build a project that met the need of transporting people while having the least impact on the environment. This study concentrated on domestic travel and focused on an EVE comparative analysis of high-speed passenger rail and interstate passenger car transportation.

Delimitations

1. Although the methodology used in this dissertation is applicable to other sites, the conclusion is site specific. As such, future sites should be analyzed independently of the data obtained for this project. Items that could impact the analysis include the following:
    a. Population density
    b. Number of rail cars in the train set
    c. Frequency of train service
    d. Typical design detail for rail line and interstate highway
2. The following items have been excluded from the one mile project length:
    a. Entry and exit ramps

b. Gas stations

c. Passenger terminals

d. Maintenance yards

Limitations

The focus of this proposal was restricted by the application of the following limitations:

1. Limiting it to two modes of passenger transportation consisting of high-speed passenger rail and interstate passenger car transportation.
2. The evaluation for each alternative was limited to one mile in length.
3. Evaluate the criteria for the construction of double railroad tracks. The use of double tracks facilitated unimpeded movement in both directions and simulated the existing use of the interstate system by passenger cars.
4. Evaluate the construction of two travel lanes in each direction of the interstate. This approach was consistent with the current use of the interstate system by passenger cars.
5. For the purpose of this study, it was projected that each automobile would carry 1.59 passengers per vehicle, (U. S. Department of Energy, 2010).
6. Although the Amtrak Acela train set was proposed for utilization in this study, it was noted that Amtrak planned to replace the Acela line rather than upgrade it (Smith, 2012). To date, Amtrak has not identified a manufacturer for the replacement train set. Amtrak Acela (2012) indicated that each Acela train set consists of :

   a. Power car: 2 (one front and one rear)

   b. Passenger Rail Cars

      i. First class: 1 (seats 44)

      ii. Business class quiet: 1 (seats 65)

iii. Business class: 3 (seats 65)

iv. Café/Bistro car: 1

c. This version of Amtrak's train set carried 304 passengers per trip. A review of the North Carolina's Amtrak by train website (n.d.), indicated that four trains operate between Raleigh, North Carolina and Charlotte, North Carolina in an approximate 12-hour period. Using the Acela train set, this equated to a passenger carrying capacity of 1,216 passengers in an approximate 12-hour period.

7. The North Carolina Department of Transportation (2004) indicated a total count of 15,867 northbound passenger cars and a total count of 19,059 southbound passenger cars in a 12-hour period passed through survey site five (Centergrove) along Interstate 85. For pavement design purposes, the traffic count at survey site five (Centergrove) was projected at a 2014 average daily traffic (ADT) of 39,114 and at a 2034 ADT of 48,633 with 6% duals and 12% truck, tractor and semi-trailer (TTST) (C. Morrison, personal communication, February 21, 2014). For this evaluation, automobiles accounted for approximately 80% of ADT which yielded 31,291 vehicles per day. The U. S. vehicle occupancy rate was an average of 1.59 passengers per car (U. S. Department of Energy, 2010). The interstate option would yield an average transport level of 49,753 passengers in a 24-hour time period or 24,876.5 passengers in a 12-hour period.

8. High-speed passenger rail and interstate passenger car alternatives were compared based on EMERGY per passenger mile.

9. The evaluation of greenhouse gas emission could be based on a composite analysis and incorporation of existing data as obtained from the EPA, the U. S. Department of Transportation, applicable designers, and manufacturers for automobiles and high-speed

passenger trains. This was acknowledged as future areas of research for incorporation into a modified EVE analysis. The term developed in this proposal to define that analysis is a Comprehensive Environmental Return on Investment (CE-ROI).

10. It was noted that interstate highway design utilized truck traffic rather than automobile traffic as a determinant for base and pavement thickness. As such, the design utilized in this study exceeded that required to exclusively transport automobiles (C. Morrison, personal communication, February 21, 2014).

Purpose of the Study

This research project focused on an environmental value engineering analysis of high-speed passenger rail transportation and interstate passenger car transportation. It ultimately determined which alternative had the least impact on the environment while meeting the need of transporting people. When transportation is viewed from a broad-based perspective, there are four categories by which people commute in the United States; air, interstate, rail, and maritime (Rodrigue, Comtois, & Black, 2013). The interstate corridor provides a venue for passenger cars, buses, and trucks. However, the method utilized in this research focused on passenger cars. The initial impetus to construct an interstate system occurred in the late 1930s when President Roosevelt submitted a report to congress (Weingroff , 2013). Funding to construct the interstate highway system was signed into law by President Eisenhower in 1956 and was known as the Federal Aid Highway Act (Glass, 2012). Among the reasons given to substantiate this allocation were national defense and safe passenger travel. This standardized transportation system would afford the ability to transport military machinery across the country with ease. The funding mechanism was leveraged by increasing the gasoline tax by $.01 a gallon. Although Congress authorized studies to evaluate the need and ultimately justify the above decisions, the reports did not consist of an environmental evaluation of a built alternative to the interstate highway system.

The transcontinental railroad was completed in 1869 and facilitated transcontinental travel at a reduced cost and at an accelerated pace (Goddard, n.d.). The construction of the railroad facilitated the movement of freight and people and subsequently accelerated the western movement of civilization to include an increase in immigration (Harvard University Library, 2013). Although the United States subsidized the construction cost, the decision to build the transcontinental railroad was not evaluated from an environmental impact perspective but focused primarily on the ability to provide a transportation mechanism to expand westward. This construction project is considered by many to be one of the greatest achievements of the 19th century (Union Pacific Railroad, 2009).

In 1970, the U. S. Congress passed the Rail Passenger Service Act for the purpose of establishing intercity passenger rail service (Amtrak, 2012). Subsequently, the for-profit corporation, the National Railroad Passenger Corporation (Amtrak) was created and continues to operate today with increasingly expanded services (Amtrak, 2012). Although Amtrak was founded on the premise that it would be a for-profit corporation, the actions of its various CEOs indicates that the company has not made a profit, nor is it capable of being a profitable organization (Loving, 2009). Puentes, Tomer, and Kane (2013) compiled a report that produced the following findings in regards to Amtrak's performance:

1. Ridership has increased 55% since 1997. This growth rate exceeds that of other major modes of transportation.
2. Ninety percent of Amtrak's ridership is generated in the 100 largest metropolitan areas.

3. Ten metropolitan areas are responsible for 2/3 of the volume.
4. Short distances (less than 400 miles) dominate ridership and profitability.

It is not the position of this study to emphasize that the above projects should not have been built; yet, it is the position of this study that by analyzing major projects from an environmental impact perspective, there is an additional tool to ensure that project alternatives are evaluated for minimal environmental impact prior to being implemented. This information can help formulate equitable infrastructure development that may ultimately consist of a combination of alternatives. Although numerous processes exist to facilitate an evaluation of a major built alternative, to date an EVE analysis has not been utilized to evaluate interstate passenger car and high-speed passenger rail transportation alternatives to determine which has the least impact on the environment while meeting the need of transporting people.

The National Environmental Policy Act (NEPA) was signed into law in 1970 by President Nixon (National Environmental Policy Act, 1970). The purpose of the act was to ensure that federal agencies evaluated the impact that their projects would have on the environment and receive a favorable record of decision prior to the construction process. Although this act was passed, it did not stipulate any single method that could be utilized to conduct an Environmental Impact Study (Council of Environmental Quality, 2007). The NEPA process is applicable to a variety of federal actions such as (a) federal construction projects, (b) plans to manage and develop federally owned lands, and (c) federal approvals of non-federal activities such as grants, licenses and permits.

It is noted that project approval through the NEPA process does not guarantee a successful project, and this process is often not without legal challenge. The Army Corps of Engineers was successfully sued during the preparation of their Environmental Impact

Statement; they were ultimately granted permission to construct the levees in New Orleans after they revised their final document (Kysar & McGarity, 2006). This document discussed potential causes for levee failure but ultimately emphasized the need to carefully study the reasons for failure that could include inadequate design, improper maintenance, and incorrect alignment to ultimately determine if a cost effective system could have been constructed to withstand the force of Category 4 or 5 storm events. In a review of the effectiveness of the NEPA process, it was determined that the document was designed to formulate the successful integration of the natural and social sciences throughout the planning and decision making processes (Bronstein, Baer, Bryan, Dimento, & Narayan, 2005).

An additional aspect that supported the need for this study was related to the sustainability of built environment alternatives. In an article that analyzed deadly combat over natural resources; hydrocarbons, gem stones, and drugs were identified as three primary natural resources that are central to armed conflict and subsequent deaths (Lujala, 2009). As it relates to the carbon footprint, there is a philosophy known as shrink and share or contraction and convergence. It focuses on reducing mankind's carbon emissions to an agreed upon level. Once that level is reached, the next agreement is based upon how the reduction in greenhouse gas emissions will be allocated between nations (Kitzes et al., 2008). An analysis of the global biodiversity indicated that international cooperation is required at levels such as the United Nations in order to ensure adequate protection of natural resources from climate change (Lee & Jetz, 2008). Based upon projected global outlooks such as these, it would be prudent for architects, engineers, and owners to begin a progressive program that automatically incorporates an environmental evaluation for major built environment alternatives. The ultimate purpose of the analysis would be to determine which had the least impact on the environment while meeting the required need. Academia offers a primary platform for change given the fact that students represent the future. Positive impact can be achieved by incorporating this approach as part of the curriculum while simultaneously presenting it to professional societies for incorporation into the standard principles and practices.

Assumptions

The following basic assumptions were made in an effort to facilitate a consistent and standardized approach to the analysis.

1. The transportation alternatives were considered for areas that have the passenger volume to justify the project.
2. The final analysis of this rubric focused on EMERGY per passenger mile. The alternative with the least EMERGY per passenger mile met the need of transporting people while having the least impact on the environment.
3. The owner's will have a budget that is sufficient to build the project.
4. All issues associated with right-of-way acquisition have been resolved.
5. The projects will receive a favorable record of decision through an approved National Environmental Policy Act process.

Definition of Terms

Comprehensive environmental return on investment (CE-ROI): The return on investment that considers a sustainable environment through the application of an EVE analysis, greenhouse gas emissions, and other applicable weighted average variables as determined by the analyst. This phrase was developed and copyrighted during this research process.

EMERGY: Coined by Scienceman (1987) and defined as transforming energy of different types into energy of one type. Odum defined EMERGY as "available energy of one kind previously required directly and indirectly to make a product or service (units: emjoules, emkilocalories, etc.)" (Odum, 1998, p. 4).

Embodied energy: The total energy required to produce a good or service to include extraction, transportation and production that can be summarized through input-output analysis and defined as embodied energy (Costanza, 1980).

Energy quality: Odum noted that the ability of energy to do work depends on its quality and quantity. He further defined the energy scale as one that "goes from dilute sunlight up to plant matter, to coal, from coal to oil to electricity and up to the high quality efforts of computer and human information processing" (Odum, 1974, para. 34)

Environmental complexity factor (ECF): A phrase developed and copyrighted for this study which correlates the time it takes an organization or agency to make a decision related to the environment. The more complex the analysis, the longer it takes an organization to make a decision. This is evident by many projects being placed on hold for an indefinite period of time in an effort for a political group to avoid the ramifications of the outcome independent of the pending impact to the environment.

Environmental value engineering (EVE): Is a methodology developed by Roudebush (1992) that is utilized to conduct an environmental life cycle cost analysis that accounts for inputs to the built environment alternatives over 10-life cycle phases.

Greenhouse gases: Gases that allow sunlight to enter into the earth's atmosphere and subsequently prevent it from being reflected off the surface and back into space as a result of absorption. This results in an increase in the earth's temperature.

Maximum empower principle: A principle that determines which economic and ecological systems will survive and contribute to future systems based on their ability to prevail in competition with each other and develop the most useful work with EMERGY (Odum as cited in Hau & Bakshi, 2003)

Net energy: Energy's true value to society and is defined as "the difference between energy yield Y and the feedback F, where both are expressed as equivalent energy units" (Odum, 1977, p. 261).

Solar EMERGY: The solar energy required directly and indirectly to make a product or service with units of solar emjoules (Odum, 1995).

Description of Transportation Alternatives

Railway Transportation Alternative

This study focused on two primary modes of transporting people—high-speed passenger rail and interstate passenger car transportation. Lowe, Tokuoka, Dubay, and Gereffi (2010) categorized passenger rail into three categories.

1. Intercity passenger rail—long distance travel linking cities with a service speed of 50 – 110 mph.
2. High-speed rail—trains traveling at speeds of 80 mph to an excess of 155 mph and linking cities at short, medium, and long distances.
3. Regional rail—also known as commuter rail, travels at short distances within metropolitan areas at speeds of 30 – 125 mph.

Ewing and Hewitt (2009) drafted a report for the American Association of State Highway Transportation Officials that broadened the definition of passenger rail to include the following:

1. A high-speed rail corridor—includes transportation speeds in excess of 110 mph and corridors of less than 500 miles.

2. A regional corridor—includes transportation speeds of 79 – 110 mph and corridor lengths of less than 500 miles.
3. Long-distance service—corridor lengths in excess of 500 miles.

The categories outlined above indicate that there is not a set standard in terms of definition or performance characteristics as it relates to classifications of passenger rail. However; one can define the parameters that are to be evaluated and, therefore, manage expectations based upon a standard set of criteria when discussing passenger rail.

Based upon the categories, there was some overlap in the speed of movement and corridor length; however, this research focused on high-speed passenger rail as generally defined above. Lowe et al. (2010) identified Amtrak's Acela line as the provider of high-speed rail service in the United States. Additionally, it was noted that this train set had a capacity of 304 seats and operated in the northeast corridor using a diesel electric power source with a grid connection. High-speed rail connects cities of varying distances. EVE was utilized to evaluate its environmental impact relative to that of interstate passenger car transportation. This determined which had the least impact on the environment while meeting the need of transporting people.

The design criteria for railroad and interstate cross sections were presented in this study. The literature review process examined the design criteria further and included final recommendations for a double-track standard detail as well as comparable interstate design criteria.

Although railroad right-of-way varies, the typical minimum is 100 feet (Schmick & Strachota, 2006). An increase in right-of-way width results in an increase in the margin of safety for reduced damages from derailment; however, the additional proposed right-of-way has an increased acquisition cost to the sponsoring agency. Figure 1 shows rail criteria design established for this research project and is modified from the CSX design criteria for private side tracks (CSX Transportation, 2007) for subballast and cross tie spacing.

1. 15-foot centerline to centerline of track
2. Each track bed is 15 feet in width
3. Minimum of 1 foot of ballast
4. Minimum of 6 inches of Subballast
5. Compacted soil bed
6. Cross ties are on 24" centers
6. 136 lb/yard rail
7. 100 foot right-of-way

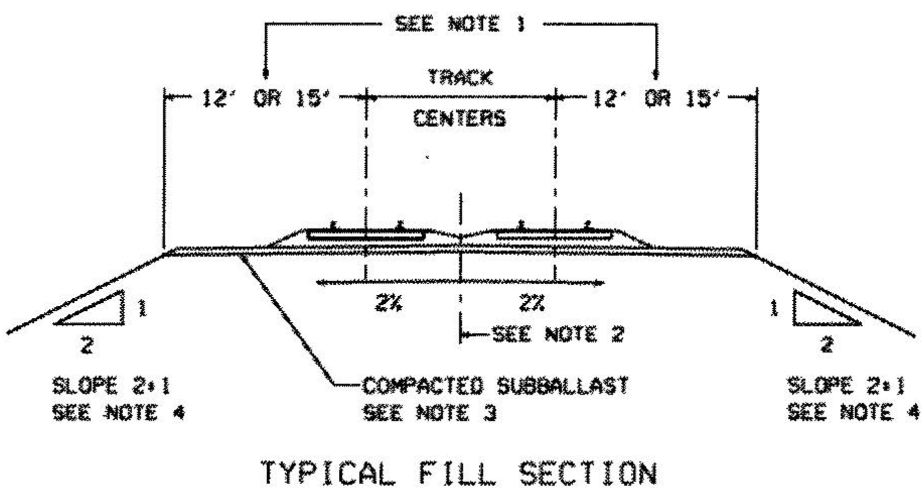


Figure 1. CSX Double track profile.

Voelker and Clark (2008) documented the North American rail asset life of various rail components for five Class - I railroads. The average data for the major components is summarized in Table 1.

Table 1

North American Rail Asset Life Summary

Component	Minimum Asset Life
Timber Sleepers/Crossties	20 – Years
Jointed/Bolted Rail	40 – Years
Ballast	25 – Years

Borchardt (2010) established the average life of concrete ties as 55 to 60 years. The article also indicated that concrete cross ties are preferred in high-speed rail to facilitate the sustained speeds associated with this method of transportation. Jeong (2012) stated that concrete tie life is less than 50 years; this was based on research and development that was conducted on Amtrak derailments. The California High-Speed Rail Authority developed a 50-year life cycle model and documented asset lifecycles based on the International Union of Railways (UIC) and the European Investment Bank (EIB), (California High-Speed Rail Authority, 2014). This data comprised the asset life for major rail system components and were utilized during the EVE analysis and subsequent application of a transformity index to calculate the total EMERGY for this transportation alternative. An overview of asset life for high-speed rail components for this study is as follows:

- Ballast – Year Zero: Original Installation
- Ballast – Year 16: Cleaning
- Ballast – Year 33: Cleaning
- Concrete Ties – 50 Years

- Rail – 50 Years

The following design criteria were derived from Caltrain Engineering Standards and Design References (2011).

- Subballast – Minimum 6 inches graded aggregate base
- Ballast – Use minimum of 12 inches from bottom of tie

Interstate Highway Transportation Alternative

Mertz (2012) indicated that in 1938, President Franklin D. Roosevelt commissioned a committee to evaluate the need for a national road system. As of 2002, there were approximately 42,787 miles of interstate highway in the United States (U.S. Department of Transportation, 2013). Although the interstate system serves a multitude of transportation purposes, this research focused on passenger car transportation.

The interstate highway system was built to serve multiple functions. Some of the reasons that justified its' construction included the need to address population growth, reduce accidents, and enhance national security while putting people to work (Cox & Love, 1996). Today, the emphasis of building additional interstate systems seems to focus primarily on moving people from point to point utilizing connectivity while increasing safety, decreasing congestion, and providing stimulus for future growth (Grace et al., 2012). The report further indicated that highway safety is now the nation's primary public health challenge and outlined the following applications as part of an Intelligent Transportation System (ITS).

1. Vehicle-to-Vehicle (V2V) Communications for Safety – Improve communication between vehicles.
2. Vehicle-to-Infrastructure (V2I) Communications for Safety. – Enhance transfer of communication from infrastructure to vehicles.

3. Real-Time Data Capture – Increase efficiency of data collection and management.
4. Dynamic Mobility Applications – Assists in effortless transfer between different modes of transportation.
5. Road Weather Management – Evaluates current weather conditions.
6. Applications for the Environment Real-Time Information Synthesis (AERIS) – Evaluates anonymous tailpipe data.

Figure 2 shows a typical interstate highway system with two lanes of travel in each direction (White, 2002). This is a typical section for rural interstate (intercity) travel and is complete with guard rails to separate the lanes. By utilizing guard rails, the designers were able to minimize right-of-way width for this section of highway. The minimization of right-of-way has a direct result of reducing the cost of acquiring additional land and also offers the ability to minimize the impact that the footprint of the interstate highway has on the surrounding environment. An abundant amount of available land at a reasonable cost minimizes benefits that can be realized from using a minimum right of way width; however, in areas where available land is scarce due to inflated cost or existing obstructions, this option becomes a very attractive alternative.

Figure 2. Typical interstate highway system (White, 2002).

Figure 3 shows typical components for an interstate highway paving section with asphalt pavement (C. Morrison, personal communication February 21, 2014). As with rail, the right-of-way for an interstate highway varies per location and is, therefore, design specific. Leisch and Mason (2005) stated that the right-of-way for a four- to six-lane rural freeway may vary from 300 to 400 feet. Based on the utilization of that design criteria, a right-of-way width of approximately 350 feet was utilized for the purpose of this analysis.

Roudebush (1996) prepared an EVE analysis that compared concrete and asphalt highway pavement systems and determined that the asphalt pavement system had the greatest impact on the environment. Based upon those results, the asphalt pavement system was used in this study and supported with data from the Roudebush (1996) analysis.

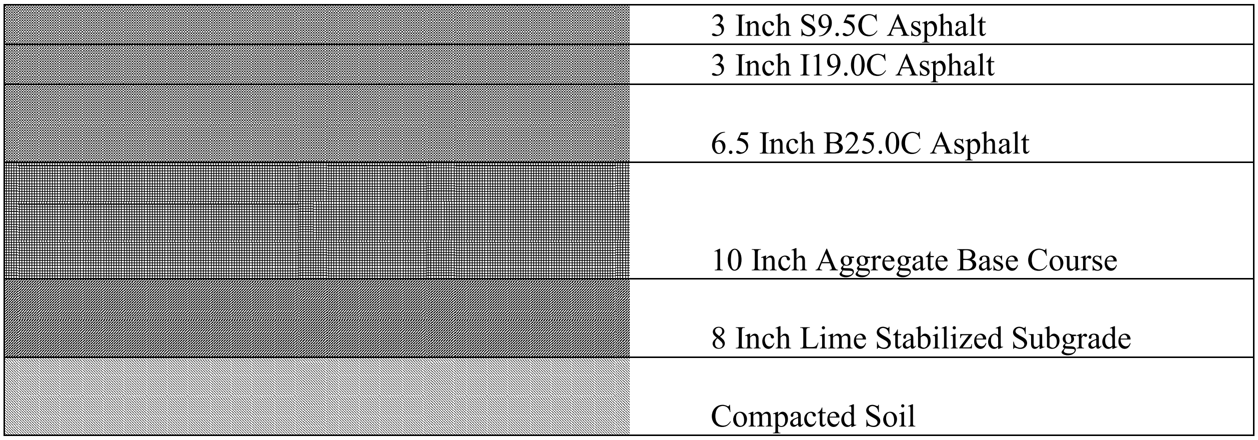


Figure 3. Typical asphalt pavement cross section.

Table 2 shows the component asset life for the asphalt pavement section. At time zero, the original asphalt pavement construction begins with a 30-year design life. It is anticipated that milling and replacement will occur at years 12, 23, and 34. The end of the use phase analysis occurs at year 54. Although the analysis ends, it is not anticipated that the interstate will be demolished. The projection is that an additional analysis will be conducted to evaluate the steps necessary to extend the useful life of the project (C. Morrison, personal communication February 21, 2014). With this scenario, the significant milestones for pavement component sequencing occur as outlined in the Table 2.

The lane widths used in this design include two 12 foot lanes, a 10 foot right shoulder and a four foot left shoulder for each direction of travel. The 10 foot right shoulder provides an area for vehicles to pull over in the event of an emergency. The four foot left shoulder allows recovery time in the event a vehicle unexpectedly leaves the highway. Based upon this approach, each direction of travel will have an asphalt footprint of approximately 38 feet in width.

Table 2

Typical Asphalt Pavement Component Sequencing

Year	Asphalt Pavement Component Sequencing
0	Initial construction with 30-year design life
12	Mill and replace 1.5 inches of surface and fog seal shoulders
23	Mill and replace 1.5 inches of surface including shoulders
34	Mill 3 inches and replace with intermediate course and 2 lifts of surface
54	End of use phase analysis

Typically, there are four major methods of project delivery; design-bid-build, design-build, construction management at risk, and integrated project delivery (Construction Management Association of America, 2012). Roudebush (1992) identified 10 EVE phases of a built environment alternative life cycle: natural resource formation, natural resource exploration and extraction, material production, design, component production, construction, use, demolition, natural resource recycling, and disposal.

Although transit plans include alternative modes of moving passengers, to date an EVE analysis of these proposed built alternatives has not been conducted. This study provides a viable tool for policy makers to use during their decision making process.

Significance of the Study

When one considers the decisions that were made during the evaluation and construction process for each of the historical transportation initiatives, it is realized that the scenarios are distinctly different in regard to alternative solutions. There was not an alternative solution to the transcontinental railroad because automobiles had not reached an effective level of development and utilization. However; during the construction of the interstate system, major rail lines were in place and functioning. A more relevant analysis is needed for the modern day construction expansion in which one has reliable transportation in the form of automobiles and passenger rail. Given the current functioning modes of transportation, it is vital that a comprehensive analytical tool such as EVE is implemented to ensure that resources are maximized in a sustainable manner while simultaneously meeting the need of transporting people. By doing so, society will have substantiated the due diligence for sustainability by evaluating the environmental impact of the alternatives. This will maximize the return on investment for people as well as the environment. The application of an EVE analysis as an additional decision-making model for major infrastructure improvements can ultimately reduce the environmental complexity factor (ECF) for policy makers.

Organization of the Study

This research determined which built environment alternative, high-speed passenger rail or interstate passenger car transportation, had the least impact on the environment based on an analysis of their total EMERGY per passenger mile and also determined if there was a significant difference in the total EMERGY values for environment, fuel energy, goods and services over the 10 phases for each transportation alternative.

Chapter 1 consisted of the importance of the study and its potential benefit to policy makers that have responsible charge of large scale projects. This chapter also included the problem statement, the purpose of the study, and a list of assumptions. The general criteria used to establish the typical design details for each transportation alternative are defined in this chapter. This established the criteria for the project limits and included supporting justification for design parameters that were ultimately used for the analysis.

Chapter 2 consists of the review of literature which includes some alternative analytical processes that can be used to conduct this analysis and a statement of their applicability. The alternative processes included life cycle cost analysis, value engineering, embodied energy, EMERGY, ecological footprint, carbon footprint, ecological economics, and EVE. As a result of this analysis, it was determined that EVE offered the most comprehensive assessment for evaluating the environmental impact of the transportation alternatives.

Chapter 3 consists of the methods and procedures that were utilized in this research project. This chapter provides an understanding to the energy systems diagram, aggregated EMERGY diagrams, and the EVE EMERGY analysis tables. It concludes with a presentation of the assessment methods that were used to evaluate each built environment transportation alternative. In addition to the EMERGY analysis, a multivariate analysis of variance (MANOVA) was utilized to determine if there was a significant difference in the solar EMERGY inputs of environment (E), fuel energy (F), goods (G), and services (S) of the two transportation alternatives. If it was determined that there was a significant difference between E, F, G and S, an independent sample *t* test would have been utilized to look at the items individually.

Chapter 4 presents the results of the comparative analysis. The data is presented in aggregated EMERGY input source data tables for the high speed rail and interstate passenger car alternatives. Additionally, a MANOVA was utilized to determine if a significant difference existed in the alternatives. The alternative with the least total EMERGY per passenger mile was the one that had the least impact on the environment while meeting the need of transporting people. This information will be very beneficial in evaluating the ultimate impact that large project alternatives have on the environment. An evaluation of this type will increase the ability for an organization to make decisions that positively impact sustainable design and construction alternatives.

Chapter 5 discussed the results (findings) and then outlined future areas of research that could be conducted in an effort to advance the progress of this study and address areas beyond the scope of this research project. This chapter is forward looking and identified direct and relevant aspects for areas of improvement in sustainable design, construction, and financing of large scale projects in the built environment.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The purpose of the review of literature was to evaluate the potential use of various processes available for analyzing the environmental impact of built environment alternatives. It determined whether the unique application of EVE is an applicable approach for evaluating high-speed passenger rail transportation and interstate passenger car transportation to determine which has the least impact on the environment while meeting the need of transporting people.

Passenger Movement by Rail and Interstate Highway

The review involved a search for relevant documents comparing high-speed passenger rail transportation to interstate passenger car transportation. The purpose of this review was to determine the potential benefit of this comparative analysis relative to the decision-making process for large project development in terms of environmental sustainability. Cox and Love (1996) stated that New York City had the greatest dependence on urban rail transportation of all U. S. metropolitan cities; however; the market share in person trips for the interstate highway system was almost double that for the passenger rail system. The Texas Department of Transportation (1999) issued a study to evaluate the feasibility of intercity transportation alternatives. Although the study found that commuter rail was a feasible alternative, it was limited to using existing rail right-of-way and was not a direct comparative analysis of high-speed passenger rail and interstate passenger car transportation (Texas Department of Transportation, 1999).

A review of the report outlined a comparison of commuter rail and interstate highway between Austin and San Antonio. Based upon this report, the measures used to reach a decision were cost effectiveness and objectivity. At the conclusion, the author summarized that air pollution was no longer a problem due to the increased efficiencies of automobiles. The report used the following evaluation criteria in its analysis: mobility improvements, environmental benefits, operating efficiencies, cost effectiveness, transit supportive land use patterns, local financial commitment, and other factors such as long-range economic viability. The report sought to expand transportation alternatives by maximizing the use of existing rail corridors and, therefore, it was not a comprehensive tool that could be utilized to compare high-speed passenger rail and interstate passenger car transportation to determine which had the least impact on the environment while meeting the need of transporting people.

O'Toole (2009) published findings that substantiated his opinion that high-speed rail is not equivalent to interstate travel. He stated that high-speed rail increases energy consumption and greenhouse emissions. He further presented a chart that showed that interstates were more expensive to build but were 10 times more efficient at moving people than high-speed rail. From an environmental perspective, O'Toole stated that as a result of Amtrak trains being 15% less energy efficient than automobiles, the Florida High Speed Rail Authority chose the no-build alternative. Since this paper evaluated air pollution, fuel savings, and construction costs from a broad-based perspective, it did not provide a comprehensive analysis of the transportation alternatives impact on the environment. Janic (2003) prepared a special issue paper that compared high-speed rail and air passenger transportation in the European Union. Although he conducted an environmental analysis, Janic did not compare high-speed rail and interstate passenger car transportation over a complete life cycle. Janic (2003) analyzed the following components to develop an environmental performance analysis in which he determined that high-speed rail had a better environmental performance than air-passenger travel—energy consumption, air pollution, noise, land-take, land use, safety, and congestion.

Bezdek and Hannon (1974) performed an analysis of the outcome if the $5 billion highway trust fund budget for that year was reinvested in five other federal programs. One of the programs consisted of investing in rail and other mass transit rather than highway construction. The result indicated a 62 % reduction in energy demand and a projected labor increase of 3%. The evaluation criteria utilized in this analysis consisted of dollars, tons of coal, gallons of gasoline, electricity in kilowatt per hour, and natural gas in cubic feet. The analysis did not include environmental impact.

Hirst and Moyers (1973) performed a transportation efficiency analysis in which they determined that passenger rail was more efficient than passenger car transportation. For that time period, they indicated that the federal government invested in passenger car, air, and highway construction but did not invest in rail or railroad construction. The units used for evaluation consisted of total energy BTU's and total cost. The analysis did not include environmental impact.

Litman (2012) published a study that evaluated rail transit and alternative means of transportation including large rail, small rail, and bus. However; the analysis focused on high-end transportation and did not evaluate the environmental impact associated with either mode. Litman utilized cost, assessable land use, energy and emissions, economic development, and safety to analyze alternatives. This was not a comprehensive analysis and cannot be used to evaluate the environmental impacts of the proposed transportation alternatives.

Funding Authorizations

The Pacific Railroad Bill was presented to Congress, signed into law by President Lincoln in 1862, and subsequently provided a funding mechanism for the construction of the transcontinental railroad (Lu, 2007). The decision to ultimately construct this project was based on benefits such as increased military capability, increased ability to move passengers and cargo, and the enhancement of international trade. The Urban Mass Transportation Act of 1964 was signed into law by President Lyndon B. Johnson (Peters & Woolley, 1964). The president emphasized the value to be gained by establishing opportunities to advance urban mass transportation through the enhancement of relationships in the public and private sectors. This act facilitated the federal government's ability to participate in mass-transportation development in urbanized areas. At the time that the act was signed, President Johnson indicated that 70% of Americans lived in urban areas and that there was a dire need to relieve the congestion associated with highway travel.

Perl and Calimente (2011) completed a report that evaluated the feasibility of integrating high-speed rail into North America's transportation network. They indicated that although the 2009 American Recovery and Reinvestment Act had allocated approximately $8 billion in grants, there was not a national policy to develop and implement a comprehensive infrastructure. The differences of political opinions and clarification of the ultimate role that Amtrak has in North America's passenger-rail services will have to be resolved before a comprehensive high-speed passenger rail program has the viability for implementation. The report discussed environmental impacts of high-speed rail but did not provide background information that was sufficient to show how they were calculated or what the categories consisted of.

Overview of Assessment Methodologies

Eight methodologies have been reviewed for their relevance in conducting a comparative analysis of high-speed passenger rail transportation and interstate passenger car transportation. The results of these analyses were beneficial as a decision model for investing in major infrastructure improvements. The methodology that was ultimately chosen for the analysis had to evaluate some common items of concern.

Carbon Footprint

Greenhouse gases consist of many naturally occurring elements but due to the complexity of a composite greenhouse gas calculation, experts have focused on the primary contributors which are carbon dioxide, methane, nitrous oxide, and fluorinated gases. A further analysis indicates that the major contributors of greenhouse gases are carbon dioxide and methane. They are analyzed and converted to carbon dioxide equivalents and used as the basis for defining the carbon footprint. The EPA (2013) indicated that in 2010, carbon dioxide accounted for 84% of all greenhouse gas activities that were attributed to human activities. A further analysis of this indicated that transportation accounted for 31% of the carbon dioxide (EPA, 2013). The EPA included highway vehicles, air travel, marine, and rail as contributors to this category. Carbon dioxide remains in the atmosphere from 50 to 200 years. This length of time validates the need to be concerned about the impacts of greenhouse gases and the inclusion in mitigating conditions in the design and construction of large scale projects that have an extended duration. Another aspect of viewing the carbon footprint was to consider the amount of land and sea area required to neutralize carbon dioxide emissions. Global Footprint Network (2012a) indicated that this allowed one to view the demand that is placed on the planet. Table 3 provides an overview of the percentage of major atmospheric greenhouse gas emissions in the atmosphere.

Although there are substantiated concerns about the greenhouse gas emissions and the subsequent measurement of the carbon footprint, this analysis alone does not provide a comprehensive view of a decision model for selecting the viability of a project. Examples of omitted items would include cost of the project, the impact that each alternative would subsequently have on the environment, as well as an omission of the effective life cycle of the proposed alternatives. An analysis that is conducted solely on the basis of a carbon footprint evaluation is not the most comprehensive or beneficial model and the reason it is not recommended as the sole basis of evaluating this research project.

Table 3

Greenhouse Gas Emissions

Gas	Percent of Atmospheric Gas	Atmospheric Life
Carbon dioxide	84%	50 – 200 years
Methane	10%	12 years
Nitrous oxide	4%	120 years
Fluorinated gases	2%	1 – 50,000 years

Ecological Footprint

Carbon footprint focuses on the impact that development has on the environment as a result of the greenhouse gases that are generated; Rees and Wackernagel (2008) proposed this question in regard to ecological footprint—"How large an area of productive land is needed to sustain a defined population indefinitely, wherever on earth that land is located?" This conceptual thought was expanded by Rees and Wackernagel to correlate to the additional acreage needed to provide all of the necessary resources to sustain a city. As a result of this thought process, one can readily conclude that based on the Earth's continued population growth; there is a sustainable limit in regard to the population that the earth itself can sustain. According to the Global Footprint Network (2012b), humans are currently utilizing 1.5 planet equivalents for resource provision and waste absorption. Since the preindustrial era, carbon dioxide in the atmosphere has increased by approximately 40%. This can be attributed to fossil fuel combustion, deforestation, and land use change (Doney, 2010). This analysis indicates the need to reverse the trend and adopt a more sustainable lifestyle in an effort to reduce the impact on the Earth's limited resources.

Urban sprawl has various impacts on the availability of services and ultimately challenges providers to deliver efficient and cost effective solutions to the residents of urban America (Clean Water Action Council, 2013). Nechyba and Walsh (2004) reviewed data from 1950 to 1990 and the results showed a decrease in population densities for cities and suburbs. The resulting overall population increase of a region and subsequent population decrease of cities within that region has contributed to urban sprawl. The increased tax burden results from challenges placed on the delivery of services. The economy of scale plays a role when one attempts to implement a consolidated transit plan, wastewater treatment facility, water generation plant, or a transportation corridor for passengers. An increase in air pollution results from additional vehicles on the road and the associated miles that vehicles are driven. As a result of the low number of riders in outlying urban areas, transit options for rail and bus are not cost effective or prudent alternatives to reducing the number of automobiles on the roadways. As urban sprawl continues to expand, municipal and county governments continue to face challenges of sustainability. A new goal and objective of future leaders will be centered on meeting the needs of residents while minimizing the impact on the environment and the budget. A conceptual planning approach will have to be developed that positions itself for a different model of delivery as the current approach is disjointed given the fact that it is being engineered in reverse and without consideration of all relevant variables. China can be viewed as a major example of the impact of unsustainable growth and development. Liu (2010) stated that in 2005, China ranked 133 of 146 in terms of environmentally sustainable countries. The United States is not without its own environmental challenges as the new technological advances of fracing/fracturing and horizontal drilling are providing access to an abundant supply of domestic natural gas (Kerr, 2010). Globally, the opposition groups should come together and devise a solution to mitigate environmental impact from existing and proposed development. The lack of consistency between nations is representative of a significant challenge to future growth and development internationally.

Although ecological footprint is widely known and has received international attention, it does not facilitate the evaluation and comparison of built environment alternatives and, as such, is not selected as the most viable method of analysis suitable for this study. When viewed from a broad-based perspective, it is envisioned that ecological footprint will be included in future studies involving a comprehensive environmental return on investment.

Ecological Economics

Faber and Bradley (1996 para. 2) defined ecological economics as “a policy-oriented perspective that addresses the interdependence and coevolution between human economies and their natural ecosystems.” This concept has generated a great deal of interest as a result of the impact that mankind's economic growth has had on the environment. As a result of man's technological advancement and ability to impact his environment, Faber and Bradley suggest that society should first determine the desired outcome. This outcome should consider the benefit to be gained and the subsequent impact that benefit will have on the environment while simultaneously evaluating a means of delivering the desired result.

Czech (2009) indicated that ecological economics gained its foundation in the natural sciences and moral philosophy to establish the ethics involved with the analysis and decision-making process. Additionally, Czech stated that there is a limit to economic growth based on the human economy relative to the supporting ecosystem. From that perspective, the focus of sustained growth must be within the constraints of what can be derived from ecosystems while implementing appropriate policy to adjust other factors accordingly. The focus of ecological economics is on the efficient allocation of resources.

Odum (1995) stated that the Earth's capacity to support people is a combination of natural constraints and human choices related to economics, environment, culture, and demography. Additionally, Odum discussed the human-carrying capacity of the Earth which he described as the maximum population that the Earth can support. This capacity can be calculated using one of six different models competing for limited natural resources.

1. Maximum region population is obtained by dividing the earth into regions and assigning a maximum population per region.
2. Mathematically fitted curves to historical populations are used to define maximum regional population.
3. The assumption of a single assumed constraint such as food can be used as a limiting factor in defining maximum regional population.

4. The reduction of multiple requirements to an amount available based on a single factor can be used as a limiting determinant in obtaining maximum regional population.
5. Population is constrained by multiple independent factors. The population is ultimately limited by a needed resource that exists in the smallest quantity.
6. Population is constrained by multiple independent factors that are described in system models.

There are flaws in the models used to calculate human-carrying capacity because not all assumptions apply equally throughout the world as it relates to people, their needs, and demands on natural resources.

Ecological economics focus on the key relationship between the limited resources and economic output. However; it does not provide a comparative analysis suitable to determine the environmental impact of two major infrastructure development projects. Although it focuses on the overall impact that man has on the ecological systems, it does not formulate that impact relative to specific projects within the built environment, and it will, therefore, not be utilized as the primary method of analysis in this dissertation.

Life Cycle Cost Analysis

Barringer (2003) described life cycle costs as cradle-to-grave costs that are summarized as an economics model of evaluating alternatives for equipment and projects. These costs represent a summation of items associated with equipment or buildings from inception to disposal or decommissioning. The summation of costs must be analyzed in net present value (NPV) dollars. This provides standardization for analysis with the decision model focusing on the selection with the smallest total NPV. The analysis summary states that the selected alternative would ultimately have the least fiscal impact of ownership or implementation over the life of the project. This information is ultimately utilized to support a justification for action. Through the application of life cycle costs, particular benefits can be realized. However, a limiting application of use becomes the fact that costs are the primary factor of determination for life cycle cost analysis. Fuller (2010) noted that life cycle cost has limitations in regard to the development or allocation of a budget.

Since life cycle cost is an economical analytical tool and uses money to compare alternatives, it does not have the ability to capture the environmental value of critical contributors to the success of a project. In essence, non-monetary contributors are omitted in this method of analysis. It does not take environmental impact into consideration and, ultimately, ignores sustainability in terms of meeting the need of the intended purpose while having the least impact on the environment. This is the reason life cycle cost analysis was not used in this research project.

Embodied Energy

Buranakarn (1998) noted that embodied energy analysis does not include labor or the work of the environment in producing *natural capital* as inputs for environmental services in processing waste byproducts. Costanza (1980) stated that mainstream economists are not primarily concerned about the flow of energy when calculating economic indicators. However; energy analysis recognizes this flow of energy and calculates its summation during the production of economic output, goods, and services. The total energy consists of direct and indirect energy with its summation referred to as embodied energy. In his article on embodied energy and economic valuation, Costanza (1980) noted that economic valuation and embodied energy are interdependent. If this approach is accepted, it would further support that the omission of embodied energy in the calculation of economic indicators results in an inaccurate and understated outlook. An input-output model is used to account for the total energy within a closed system. Additionally, Costanza noted that solar energy represents a principal form of energy input for the Earth. Since embodied energy does not include the work of the environment, it cannot be used as a primary method of analysis in this evaluation of transportation alternatives.

EMERGY Analysis

Odum (1995) clarified that the Maximum *Empower Principle* actually determines which system ultimately survives and contributes to the future. Brown & Herendeen (1996) implied that through competition, systems would develop the most useful forms of work based on emergy flow.

It is noted that EMERGY analysis has received extended criticism. Hau and Bakshi (2003) stated that the differences of opinions are often centered on the assumptions that must be made during the analysis; this results in an inability to link EMERGY analysis to other disciplines and, subsequently, obtain reliability across the disciplines. He did, however, note that other analytical processes that attempt to jointly analyze industrial and environmental systems are also subject to criticism. Contrary to most accepted analytical practices, EMERGY analysis does not use money as a basis of reaching a decision.

Odum stated,

> Money cannot be used directly to measure environmental contributions to the public good, since money is paid only to people for their services, not to the environmental service generating resources. Price is often an inverse to the contribution of a resource

> because it contributes most to the economy when it is easily available, requiring few services for delivery. (Odum, 1988, p. 1,136)

Brown and Ulgiati (2004) also noted that energy quality was another area that Odum's work on EMERGY received major criticism. Brown and Ulgiati further explained Odum's concept that not all energy was capable of producing equal amounts of work. Odum applied transformities to convert energy of different types into energy of one type. The application of transformities required the modeler to make a number of assumptions. Some experts ultimately developed an issue with the number of assumptions that the modelers had to make.

Various methods exist to facilitate the comparison and ultimate selection of built environment alternatives. The advantage of using EMERGY is based on its summation of differing types of energy into types of inputs such as environment, fuel energy, goods, and services. Odum (1995) stated that solar EMERGY is defined as the solar energy that is required to make a product or service. Roudebush (1992) stated that EMERGY analysis summarizes different types of energy into one type through the use of transformities for various inputs of environment, fuel energy, goods, and services. This indicated that this approach was beneficial in this research project.

Value Engineering

Value engineering was developed by Lawrence D. Miles at the General Electric Corporation during World War II and has proven to be effective in reducing cost and maximizing design and subsequent construction (University of Wisconsin-Madison, 2013). Although value engineering focuses on costs, its ultimate goal is value improvement (Department of Defense, Value Engineering Program, 2012). Value engineering can be viewed as consisting of the following three primary input variables; however, cost is a focal point of reduction.

1. Reduced cost
2. Increased quality
3. Improvement in mission capabilities/production

Although this variable is being reduced, the goal of the organization is to simultaneously increase production and product quality. From this perspective, cost is inversely proportional to quality and production. Although the federal government has successfully applied value engineering to project delivery, this tool can also be utilized in conjunction with other methods of delivery and, ultimately, add additional cost-saving measures for the organization. When firms review a project for the application of value engineering, it is understood and accepted that costs in one area may increase as long as the overall project cost decreases relative to the base project cost. Cullen (2010) indicated that there are no scheduling limitations in regard to the application of value engineering. However, as project time increases, the return on investment of value engineering decreases because of the additional costs associated with project revision.

Value engineering focuses on the three primary variables noted earlier; it does not have a means for compensating for non-cost contributors to project satisfaction such as impact to the environment, benefit gained from aesthetics, and schedule. There have been modifications made to the application of value engineering such as the assignment of a weighted value in an effort to compensate for impact items that are outside the scope of value engineering variables. It is noted that value engineering has successfully increased the value of a product while simultaneously reducing cost; value engineering does not have a component that addresses sustainability, and as such, cannot be used as the primary method in this analysis to determine which transportation alternative has the least impact on the environment.

Environmental Value Engineering (EVE)

Roudebush (1992) developed a system called environmental value engineering (EVE), which is a means of analyzing the environmental impact of built environment alternatives competing for limited natural resources. Refer to Table 4 for the EVE environmental life cycle phases.

Table 4

EVE Environmental Life Cycle Analysis Phases

Phase	Phase Title
A	Natural Resource Formation
B	Natural Resource Exploration & Extraction
C	Material Production
D	Design
E	Component Production
F	Construction
G	Use
H	Demolition
I	Natural Resource Recycling
J	Disposal

EVE is based on Odum's EMERGY analysis methodology; it also combines some life cycle aspects of value engineering. EMERGY was selected as the basic units of quantification because it takes energy of different types and converts it through transformities into energy of one type. Odum stated that "solar EMERGY is the solar energy required directly and indirectly to make a product or service (units: solar emjoules)" (Odum, 1998, p. 4). Traditional evaluations use money to compare alternatives; it can only be utilized to pay for human services and as such, does not value the environment (Roudebush, 1996). The EVE environmental life cycle analysis has 10 phases in which the sum of EMERGY contributions at each phase is cumulative to the subsequent phases. Each of the 10 phases account for all inputs to the four input categories consisting of environment (E), fuel energy (F), goods (G), and services (S).

Roudebush described the built environmental inputs relative to an EVE analysis as "all human-made objects (alternatives) on Earth that consume environment (E), fuel energy (F), goods (G), and services (S) inputs" (Roudebush, 1996, p. 2). Figure 4 shows a descriptive analysis of the built environmental inputs as modified from Roudebush (1996) to reflect the transportation system alternatives analyzed in this dissertation. Roudebush further described the life cycle such that it included all phases that a built environment alternative progresses through from natural resource formation to final disposal.

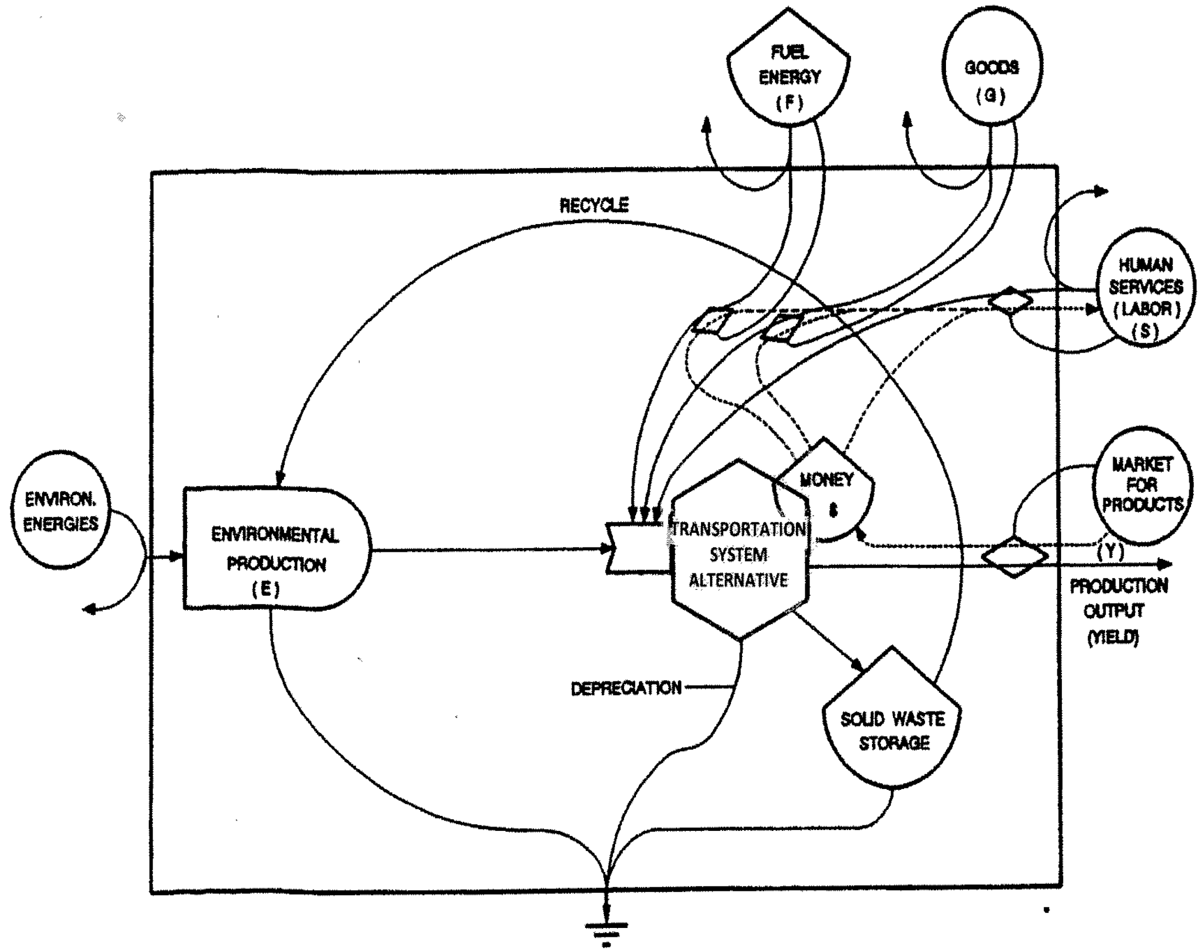


Figure 4. Energy systems diagram.

A list of the environmental impact EMERGY input sources for all 10 EVE phases is presented in Appendix A. An overview of the production and consumption processes is described in the following sections. It is noted that material transformation occurs in Phases A through C.

Phase A: Natural Resource Formation

"Natural resources utilized in built environment alternatives include minerals, which are formed by earth's processes over millions of years, and biomass, resulting from living organism net production occurring over shorter periods of time" (Roudebush, 1996, p. 7). The abundance of natural resources has a direct correlation to the potential wealth of a nation. This phase only includes EMERGY of inputs of environment.

Phase B: Natural Resource Exploration and Extraction

This phase includes EMERGY of environment, fuel energy, goods, and services inputs. Roudebush (1996) accurately predicted that the EMERGY associated with this phase would increase. As technology continues to evolve, man is able to gain access to and, subsequently, extract resources that were previously not feasible to extract. Some relevant examples of this include the use of horizontal drilling and directional drilling for natural gas (Geoscience News and Information, (2013). The extraction of natural gas using hydraulic fracturing is another example of how man is able to gain access to resources that were previously inaccessible (EPA, 2013b). As the nation continues to strive for energy independence, the demand for additional domestic resources inspires the use of intellectual knowledge and applied technology to locate and extract natural resources.

Phase C: Material Production

This phase includes the EMERGY of environment, fuel energy, goods, and services inputs. This process includes the EMERGY required to convert natural resources into materials that can be used in built environment alternative component production. Depending upon the end use and the products complexity, some materials require additional design prior to component production.

Phase-D: Design

This phase includes EMERGY of environment, fuel energy, goods, and services inputs. Depending upon the method of delivery, the architects and engineers that compose the design team may be viewed as a distinct group such as in the design-bid-build deliverable, or as a team along with the contractors such as in the design-build deliverable. However, regardless of the method of delivery, the resulting EMERGY contribution remains unchanged.

Phase-E: Component Production

This phase includes EMERGY of environment, fuel energy, goods, and services inputs. This phase primarily consists of components that are produced by a manufacturer and results in products that are ultimately delivered to a job site for use by a contractor. The location of component production can have an impact on the ultimate product selection.

Phase-F: Construction

This phase includes EMERGY from environment, fuel energy, goods, and services inputs. The construction process is where the assembly of various components occurs and includes the on-site manufacturing of some components that are used in the finished-built environment alternatives. Various methods of delivery can be utilized during the construction process; however; the EMERGY associated with the final built environment alternative remains unchanged.

Phase-G: Use

This phase includes EMERGY of environment, fuel energy, goods, and services inputs. This phase was all inclusive of activities that occur from substantial completion through to the built environment alternative demolition.

Phase-H: Demolition

This phase consists of EMERGY of environment, fuel energy, goods, and services inputs. Additionally, it was noted that as recycling efforts increased, the EMERGY associated with this phase also increased. This increase in EMERGY is associated with the additional effort required to separate comingled debris and haul it to various recyclers. Roudebush (1992) stated that one cubic yard of landfill space is required for each 1,000 to 1,200 pounds of demolition debris. Roudebush further stated that as landfill spaces decrease, the environmental policies related to the built environment impact the ultimate selection of material types.

Phase-I: Natural Resource Recycling

This phase includes EMERGY of environment, fuel energy, goods, and services inputs. Roudebush (1992) noted that the benefits of an increase in recycling would be as follows:

- An increase in natural resource formation
- A decrease in natural resource exploration and extraction
- A reduction in material and component production
- An increase in available landfill space

Phase-J: Disposal

This phase consists of EMERGY of environment, fuel energy, goods, and services inputs. The ability to increase the number of products and components that are salvaged helps maintain available landfill space. As it becomes more difficult to permit new landfills, alternative disposal methods are developed.

Applications of EVE

Roudebush (1992) developed EVE in his research through a comparison of built environment alternatives consisting of concrete masonry unit and concrete tilt-up unit wall systems. He performed an EVE life cycle assessment of concrete and asphalt highway pavement systems for the Portland Cement Association (Roudebush, 1996). Atalah, Onsarigo, and Roudebush (2012) conducted an EVE assessment of horizontal directional drilling (HDD) versus open-cut. Tenah (1996) conducted an analysis of the design and selection of materials in buildings and, further, discussed the process and the future of EVE. In his conclusion, Tenah had two recommendations for value engineers (a) take a more detailed look at the energy required to produce a product or system and, (b) calculate the true life cycle cost of all options. Johnson (2007) wrote about implementing the EVE process in the built environment and concluded that EVE should be started with the initial or conceptual phase of project development. Ingwersen (2010) used an EMERGY evaluation for his study to evaluate case studies in gold mining and pineapple production.

The comprehensive analysis of EVE that combines the application of EMERGY analysis and value engineering in which it looks at the environmental life cycle assessment over 10 phases validates the selection to use it in this study. Items for future study could include additional analytical assessments such as carbon footprint, ecological footprint, and ecological economics. The compilation of these tools along with EVE would result in a composite environmental return on investment. The final components of a comprehensive environmental return on investment (CE-ROI) are determined by the modeler.

CHAPTER 3

METHODS AND PROCEDURES:

Chapter 3 outlines and describes the methods and procedures utilized in developing the EVE analysis of high-speed passenger rail and interstate passenger car transportation as a decision model for investing in major infrastructure improvements. An important aspect of this analysis is the ultimate task of transporting people via a means that has the least impact on the environment based upon an EVE analysis. High-speed passenger rail was identified as Alternative 1 and interstate passenger car transportation was identified as Alternative 2.

At the conclusion of the EVE analysis, a multivariate analysis of variance (MANOVA) was conducted utilizing the EMERGY values to determine if there was a significant difference between high-speed passenger rail and interstate passenger car transportation that substantiated rejecting the null hypothesis. *Discovering Statistics Using IBM SPSS Statistics* (Field, 2013) was utilized as the reference source for the MANOVA analysis. If the null hypothesis was rejected and it was determined that a significant difference existed, inputs of E, F, G, and S would be compared individually to determine where the significant difference existed by utilizing an independent sample *t* test. *Statistics for Business and Economics* was utilized as the text reference for the *t* test (Anderson, Sweeney, & Williams, 2011).

The following data contained in this section of Chapter 3 was verified. The North Carolina Department of Transportation (2004) indicated a total count of 15,867 northbound passenger cars and a total count of 19,059 southbound passenger cars in a 12-hour period passed through survey site five, Centergrove, along Interstate 85. For pavement design purposes, the traffic count at survey site five (Centergrove) was projected at a 2014 average daily traffic (ADT) of 39,114 and at a 2034 ADT of 48,633 with 6% duals and 12% truck, tractor and semi-trailer (TTST) (C. Morrison, personal communication February 21, 2014). For this evaluation, automobiles accounted for approximately 80% of ADT which yielded 31,291 vehicles per day. The U.S. vehicle occupancy rate was an average of 1.59 passengers per car (U.S. Department of Energy, 2010). The interstate option yielded an average transport level of 49,753 passengers in a 24 hour time period or 24,876.5 passengers in a 12-hour period.

Although the Amtrak Acela train set was utilized for this study, it was noted that Amtrak plans to replace the Acela line rather than upgrade it (Smith, 2012). To date, Amtrak has not identified a manufacturer for the replacement train set. Amtrak Acela (2012) indicated that each Acela train set consists of:

1. Power car: 2 (one front and one rear)
2. Passenger Rail Cars
    a. First class: 1 (seats 44)
    b. Business class quiet: 1 (seats 65)
    c. Business class: 3 (seats 65)
    d. Café/Bistro car: 1

This version of Amtrak's train set can carry 304 passengers per trip. A review of the North Carolina's Amtrak by train website (n.d.), indicated that four trains operate between Raleigh, NC and Charlotte, NC in an approximate 12-hour period. Using the Acela train set, this equated to a passenger carrying capacity of 1,216 passengers in an approximate 12 hour period.

An initial review of CSX design criteria indicated that the typical right-of-way needed for double track installation was 100 feet (30.5 meters). The typical design criteria were cross-checked with the manual provided by the American Railway Engineering and Maintenance-of-Way Association (2012) and Caltrain's Engineering Standards and Design References (2011). The right-of-way width of 350 feet (106.6m) was utilized for the interstate highway. This was within the 300 to 400 foot (91.4 to 121.9m) range recommended by Leisch and Mason (2005).

The distance of each transportation alternative was limited to a typical length of one mile (1.6 km) of rural section between cities. The material composition of the train set was determined from Amtrak's high-speed rail group (B. Hastings, personal communication, January 28, 2013). Refer to Table 5 for a comprehensive overview of the material composition of an Acela train set. The information was categorized by major material components and their subsequent weights and percentages. This compilation of data could facilitate the future application of EVE which would ultimately yield the composite impact that each transportation alternative has on the environment while meeting the need of transporting people. The EMERGY values were calculated and summed over the 10 life cycle phases accounting for inputs of the environment, fuel energy, goods, and services. The alternative identified with the lowest EMERGY value per passenger mile would have the least impact to the environment while meeting the need of transporting people.

Information that substantiates such a decision could prove to be of tremendous value to decision makers that serve in various capacities. It would empower them to make sustainable decisions for major infrastructure projects and improve the utilization of the limited natural resources.

Table 5

Baseline Rail Set Material Composition – Acela Train Set

Material	Pounds	Kilograms	Percent
Plastics/Composites	25,000.00	11,345.07	2%
High Strength Steel	1,132,000.00	513,704.85	97%
Glass	14,000.00	6,353.24	1%
Total	1,171,000.00	531,403.16	100%

The material composition of an average automobile was obtained from information compiled by the Massachusetts Institute of Technology (n.d.). Refer to Table 6 for the baseline material composition of an average vehicle. The material composition data can be evaluated in future research with the appropriate transformities to yield an EMERGY value. The composite value for this alternative can be evaluated relative to the high-speed rail alternative to further determine which has the least impact on the environment while meeting the need of transporting people. As stated earlier, an evaluation from this perspective could provide valuable information for the decision makers in various capacities and ultimately maximize the utilization of the limited natural resources and subsequently reduce the impact to the environment. Additionally, the evaluation of the environmental impact that car composition has on the environment could substantially lead to the construction of automobiles with a vastly different material composition such that the environmental impact is reduced even further. This could effectively reduce the impact that final disposal has as it relates to landfill application while simultaneously increasing the ability to recycle the product at the end of its useful life.

Table 6

Baseline Vehicle Material Composition

Material	Pounds	Kilograms	Percent
Plastics	224.5	101.9	7%
Aluminum	155.5	70.6	5%
Copper	49.5	22.5	2%
Zinc	20.0	9.1	1%
Lead	0.0	0.0	0%
Other ferrous	68.5	31.1	2%
Iron	459.0	208.3	15%
Carbon steel	1387.0	629.4	45%
High strength steel	234.0	106.2	8%
Stainless	31.0	14.1	1%
Glass	85.0	38.6	3%
Rubber	134.5	61.0	4%
Fluids	179.5	81.5	6%
Other ferrous	83.0	37.7	3%
Total	3111.0	1411.8	100%

Energy Systems Diagrams

Roudebush (1992) pioneered and copyrighted an assessment system called environmental value engineering (EVE) for his dissertation at the University of Florida. This evaluation system is based largely on Dr. Howard T. Odum's EMERGY analysis methodology. A primary distinguishing characteristic of EVE is that its' outcome is not driven by money. Money circulates into the system and impacts fuel, goods, and services but is only used to pay for labor. The inputs for the built environment consist of environment (E), fuel energy (F), goods (G), and services (S). EVE evaluates the impact that a built alternative has on the environment. This evaluation is based on EMERGY and, as such, does include the valuation of money for labor in terms of EMERGY. Any influence that money exerts on the system is converted into EMERGY. Figure 4, shown in Chapter 2, could be interpreted as a bounded environmental system that is impacted by external parameters or energy input sources that are organized from left to right, starting with the lowest quality in the lower left outside systems boundary and proceeding clockwise to the highest quality. The external energy input sources consist of environment (E), fuel energy (F), goods (G), services (S), and a market for products and increase in quality in a clockwise direction. The heat sink at the bottom is utilized to show a dissipation of potential energy in the form of wasted energy (heat). The internal parameters consist of environmental production (producer), a transportation system (consumer), money (storage), and solid waste (storage). It is noted that energy quality increases as energy flows from left to right within the systems boundary. Within the boundary of the energy systems diagram, energy flows on all pathways and experiences transformation through the various productions, system alternatives, storage, and consumption processes that it encounters. Additionally, the transformation of energy increases in quality as it flows from left to right, and this transformed energy is measured based on its EMERGY value.

An EVE EMERGY analysis input table facilitates the calculation of EMERGY for the four different input categories during the 10 life cycle phases. There are two major differences between the construction of the EVE EMERGY analysis table and that constructed by Dr.

Howard T. Odum. The EVE table condensed the external components to four categories consisting of environment (E), fuel energy (F), goods (G), and services (S). The next categorical difference is that the EVE EMERGY analysis table encompasses all subsystems of the built environment alternatives through the 10 life cycle phases (Roudebush, 1996). EMERGY analyses were usually conducted for a specific area and length of time.

Aggregated EMERGY Input Diagrams

Refer to Figure 5 for an aggregated view of the external inputs of environment, fuel energy, goods, and services over the 10 EVE life cycle phases. Roudebush (1992) further stated that the EMERGY for all external inputs is summed over the 10 life cycle phases. The summation of EMERGY values in this study indicates the impact that inputs to each transportation alternative has on the environment. The alternative with the lowest composite EMERGY value per passenger mile by definition meets the need of transporting people while having the least impact on the environment. EVE evaluates environmental impacts based on total EMERGY. Any external inputs, such as labor, that involves money are converted into EMERGY using the appropriate transformities. The application of the appropriate transformity to money results in a conversion to an equivalent value of EMERGY. An analysis of the aggregated EMERGY diagram reveals the following EMERGY inputs:

Environment – Source

Fuel Energy – Tank or energy storage

Goods – Source

Services – Source

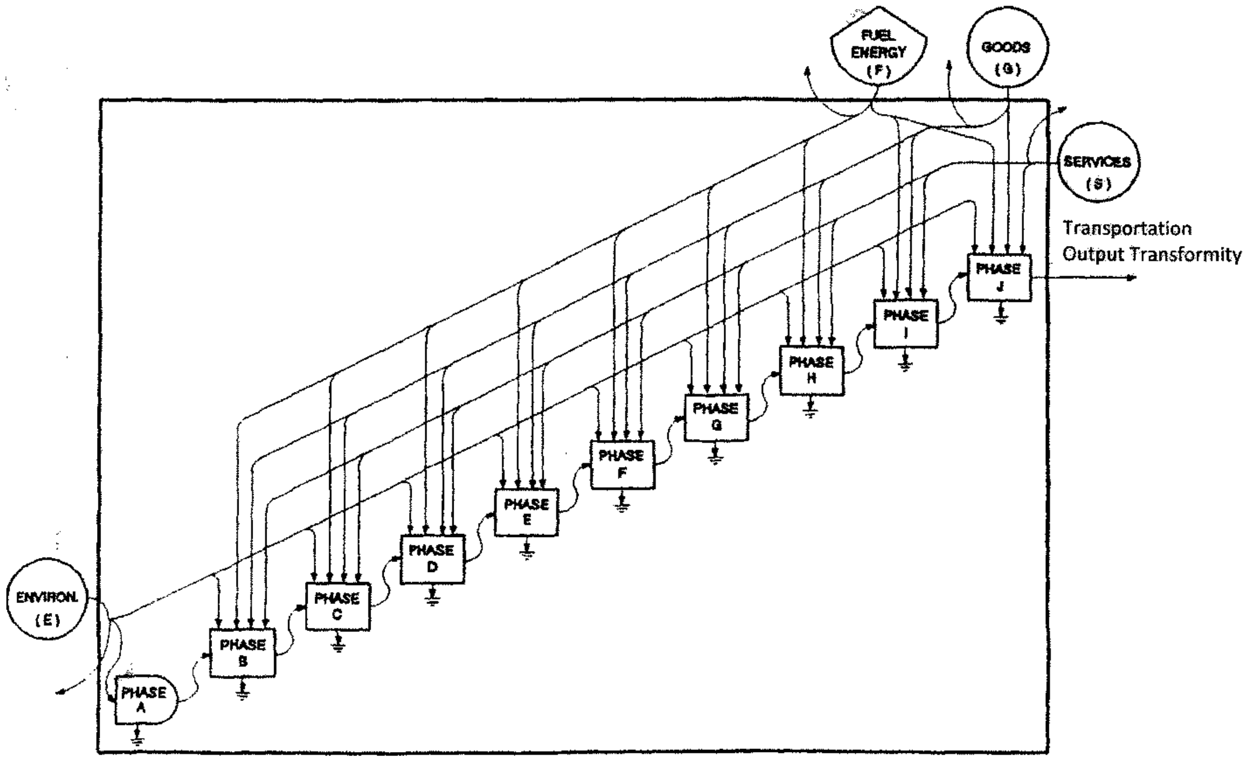


Figure 5. Aggregated EMERGY diagram.

EVE EMERGY Analysis Tables

Roudebush (1996) outlined procedures for constructing an EVE EMERGY analysis input table and those procedures have been adopted for the purpose of conducting this analysis. The tables associated with the calculations for both transportation alternatives are contained in Appendix C.

1. Each transportation alternative has its separate and distinct set of EMERGY analysis tables grouped into the four components of environment, fuel energy, goods, and services. Fuel energy may include renewable fuel energy such as solar and wind.
2. The tables are annotated such that the respective calculation sheets can be accurately matched and cross checked with composite values.

a. There are variables that will be entered into the tables with four columns outlined as follows:

    1. Input Source
    2. Item/External input
    3. Raw unit
    4. Transformity

b. The fifth column is the product of raw data units and the corresponding transformity. The resulting value is known as the solar EMERGY and is shown in units of solar emjoules (sej).

3. The values are evaluated for total impact based upon EMERGY values and annotated in the Aggregated EMERGY Input Tables in Appendix D. These tables are compiled for both alternatives and show aggregated EMERGY values for four groups over 10 life cycle phases.
4. Data from the EMERGY Input Tables can also be sorted into Composite EMERGY Values by Group. These tables are located in Appendix E and show total EMERGY values for the four external inputs of environment, fuel energy, goods and services for each alternative over the 10 life cycle phases.
5. Supporting Calculations: The data used to substantiate crew size, task duration and equipment specifications were obtained from *RS Means Heavy Construction Cost Data* (2013). Refer to Appendix G for an equipment schedule that was developed using equipment from various manufacturers that was comparable to the equipment class identified in RS Means (2013). The references for equipment weight included Caterpillar, Inc. (2012), GATX Corp. (2014), Harsco Corp. (2014), Herzog

Contracting Corp. (2010), Lay-Mor (2011), Liebherr Group (n.d.), Loram Maintenance of Way (2008), Orgo-Thermit, Inc. (2013), Praxair Technology (2014), Stanley Infrastructure (2014), Stihl (n.d.), and Vermeer (2014). The references for fuel economy included Caterpillar, Inc. (2012), GATX Corp. (2014), Harsco Corp. (2014), Liebherr Group (n.d.), Loram Maintenance of Way (2008), and Vermeer (2014),. The references for useful life included FOA Corporate Document Repository (n.d.), Orgo-Thermit, Inc. (2013), U.S. Environmental Protection Agency (n.d.).

Assessment Methods

Introduction

An EVE EMERGY analysis rubric was used to compare high-speed passenger rail and interstate passenger car transportation alternatives through a fixed distance. In addition to analyzing the aggregated EMERGY values for both alternatives, an evaluation of total EMERGY per passenger mile will be analyzed to ultimately determine which alternative has the least impact on the environment while meeting the need of transporting people. At the conclusion of the EVE analysis, a statistical evaluation will be performed to determine if a significant difference exists between the alternatives utilizing the EMERGY values from the Aggregated EMERGY Input Tables in Appendix D.

EVE Analysis

This comparative analysis was conducted using EVE. The EMERGY values for the major transportation alternatives, high-speed passenger rail, and interstate passenger car transportation, were calculated and compared. The components of a one mile (1.6 km) stretch of double railroad track were calculated in terms of EMERGY and compared to those of a comparable length section of interstate highway. Data was assimilated from the EMERGY Input Tables in Appendix C and compiled as follows:

1. Aggregated EMERGY Input Tables – Appendix D: This data shows the aggregated EMERGY values for the four external inputs of environment, fuel energy, goods and services over the 10 life cycle phases.
2. Composite EMERGY Input Tables – Appendix E: This data shows composite EMERGY values for each of the groups individually. This aspect shows the correlation for each alternative by external input.
3. The transportation option with the smallest composite EMERGY value per passenger mile would have the least impact on the environment while meeting the need of transporting people.

MANOVA Statistical Analysis

The multivariate analysis of variance (MANOVA) is a statistical analysis that is commonly used to evaluate multiple dependent variables (Tonidandel & LeBreton, 2013). This analysis contains four dependent variables (environment, fuel energy, goods and services) and two independent variables, Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives; as such, a MANOVA was selected as the statistical process. This research used IBM's software Statistical Package for the Social Sciences (SPSS) to evaluate the MANOVA. Field (2013) identified the following four assumptions that extend to multivariate analysis:

1. Independence – Statistical independence among residual values.
2. Random Sampling – Data should be measured at intervals and sampled randomly.
3. Multivariate Normality – Residuals should have multivariate normality.

4. Homogeneity of Covariance Matrices – Variances for the dependent variables should be approximately equal.

$H_{0:} : U_1 \ = U_{2:}$

$H_{a:} : U_1 \ \neq U_{2:}$

H_0: The null hypothesis states that there is no difference in terms of environmental impacts between high-speed passenger rail and interstate passenger car transportation systems.

H_a: The alternative hypothesis states that there is a difference in terms of environmental impacts between high-speed passenger rail and interstate passenger car transportation systems.

The following research questions were answered during the evaluation section of this study.

1. What is an effective methodology for evaluating the environmental impact of high-speed passenger rail and interstate passenger car transportation alternatives?
2. Which transportation alternative had the least impact on the environment while meeting the need of transporting people?

Refer to the Aggregated EMERGY Input Tables in Appendix D; they are formulated for each transportation alternative to facilitate entering the EMERGY values into SPSS. The results for the MANOVA were analyzed to determine if there was sufficient evidence to reject the null hypothesis. If the null hypothesis was accepted, it would indicate that there was not a significant difference in EMERGY values for the high-speed passenger rail and interstate passenger car transportation. If the MANOVA results indicated that the null hypothesis was rejected, it would indicate that there was a significant difference between the EMERGY values for high-speed passenger rail and interstate passenger car transportation. An analysis of variance can only be used to evaluate whether or not there is a significant difference in population means; further evaluation must be conducted to identify where the significant difference exists by utilizing an independent sample *t* test (Anderson, Sweeney, & Williams, 2011). Tables 10, 11, 12 amd 13 contain the composite EMERGY values for four external inputs of environment (E), fuel energy (F), goods (G) and services (S). If the null hypothesis for the MANOVA analysis was rejected, an independent sample *t* test would have been utilized to compare the EMERGY values of E, F, G, and S to determine where the difference existed between the two transportation alternatives. Data from the Composite EMERGY Value Tables in Appendix E would have been used to conduct the independent sample *t*-test.

The null hypothesis for the independent sample *t* test analysis states that the difference between the population means of Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives was less than zero. The alternative hypothesis states that the difference between the population means of Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives was greater than zero.

$H_{0:} : U_1 - U_{2:} < 0$

$H_{a:} : U_1 - U_{2:} > 0$

$s^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 + n_2 - 2)}$ Equation-1

$t_{calculated} = \frac{(x_1 - x_2) - (u_1 - u_2)}{\sqrt{s^2(\frac{1}{n_1} + \frac{1}{n_2})}}$ Equation-2

Degrees of freedom = $n_1 + n_2 - 2$ Equation-3

Reject H_0 if $t_{calculated} > t_{critical}$

n_1= 8, n_2= 8 and Alpha is established at an acceptable level of 0.05

In summary, Chapter 3 outlined the proposed methods and procedures that were utilized in the research. The proposed evaluation of built environment alternatives consisted of an EVE EMERGY analysis of high-speed passenger rail and interstate passenger car transportation alternatives. The focus was to determine which alternative had the least impact on the environment while meeting the need of transporting people. This decision was reached by comparing the EMERGY per passenger mile for each transportation alternative. The alternative with the smallest EMERGY value per passenger mile was identified as the one that met the need of transporting people while having the least impact on the environment. The resulting EMERGY values were further evaluated utilizing a MANOVA to determine statistically if there was a significant difference between E, F, G, and S EMERGY values from the Aggregated EMERGY Input Tables in Appendix D.

CHAPTER 4

COMPARATIVE ANALYSIS

Chapter 4 outlines and describes the results obtained from the environmental value engineering rubric that compared high-speed passenger rail and interstate passenger car transportation alternatives through a fixed distance. High-speed passenger rail was identified as Alternative 1 and the interstate passenger car transportation was identified as Alternative 2. Calculations for each alternative were compiled in the EMERGY Input Tables of Appendix C. The sums of the four inputs for the10 phases are allocated in the Aggregated EMERGY Input Tables of Appendix D for each alternative. Appendix E shows the Composite EMERGY Values by external input. The final aspect of the evaluation consisted of calculating the EMERGY per passenger mile for each transportation alternative to identify the alternative that had the least EMERGY impact on the environment while meeting the need of transporting people. At the conclusion of the EVE analysis, a multivariate analysis of variance (MANOVA) was conducted using the IBM statistical program for social sciences (SPSS) to determine statistically if a significance difference existed between the two alternatives. If the MANOVA had resulted in the rejection of the null hypothesis, indicating that the two alternatives were not equal, then an independent sample *t* test would have been conducted to determine where the significant difference existed among inputs of E, F, G, and S.

EMERGY Input Tables

Refer to Table 7, this shows how data is compiled in the EMERGY Analysis input tables for the top soil Material Transformity Phase A-C for Alternative 1(high-speed passenger rail). These tables were constructed for the four inputs of E, F, G and S over the 10 phases for both alternatives in Appendix C.

Table 7

EVE Topsoil EMERGY Analysis Input Alternative 1 (High-Speed Passenger Rail)

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY(seJ)
E	ENVIRONMENT	$16.77\ x10^9\ g$	$1.71\ x10^9$	$2.87\ x10^{19}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$2.4\ x10^9\ g$	$1.71\ x10^9$	$4.10\ x10^{18}\ sej$
G	Goods	$2.4\ x10^9\ g$	$1.71\ x10^9$	$4.10\ x10^{18}\ sej$
S	Services	$2.4\ x10^9\ g$	$1.71\ x10^9$	$4.10\ x10^{18}\ sej$

Of the items evaluated in the material transformity phases, stone was the only item that contained a transformity value for the mined state as well as an additional transformity value for the natural state. This facilitated the use of a different transformity for environment (E). When the EMERGY was calculated for other items in the Transformity Phases A-C, the transformity value was the same for all four inputs and subsequently allocated based upon a percentage of the four inputs as follows:

a. Environmental (E) – 70%
b. Fuel Energy (F) – 10%
c. Goods (G) – 10%
d. Services (S) – 10%

The items evaluated in the Transformity Phases A-C are as follows:

a. Top Soil
b. Sub Ballast
c. Ballast
d. Lime Stabilized Subgrade
e. Subgrade Sealant
f. Prime Coat
g. Tack Coat
h. Fog Seal
i. Aggregate Base Course
j. Asphalt Concrete Pavement

Aggregated EMERGY Input Table Analysis

The aggregated EMERGY input tables were developed for both alternatives in Appendix D. Table 8 contains the aggregated EMERGY input values for Alternative 1 (high-speed passenger rail). Tables 8 and 9 provide the EMERGY inputs for the MANOVA analysis. The MANOVA provides a robust statistical analysis of multiple independent variables consisting of environment, fuel energy, goods and services relative to the two independent variables identified as Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives. The MANOVA columns in Tables 8 and 9 are identified consistent with the perspective alternative to identify the dependent variables that are associated with each independent variable.

Table 8

Aggregated EMERGY Input Alternative 1 (High-Speed Passenger Rail)

	EMERGY Input Source Data (sej)				Total Phase	
EVE Phase	Equipment (E)	Fuel (F)	Goods (G)	Services (S)	EMERGY	MANOVA
A-C: Transformity	4.44×10^{19}	6.00×10^{18}	6.00×10^{18}	6.00×10^{18}	6.24×10^{19}	1
D: Design	0	0	0	0	0	1
E: Comp. Prod.	8.52×10^{20}	1.22×10^{20}	1.22×10^{20}	1.22×10^{20}	1.22×10^{21}	1
F: Constr.	1.06×10^{15}	9.50×10^{17}	3.13×10^{17}	4.97×10^{18}	6.23×10^{18}	1
G: Use	1.66×10^{13}	3.33×10^{17}	2.26×10^{16}	9.25×10^{16}	4.48×10^{17}	1
H: Demolition	0	0	0	0	0	1
I: Recycling	0	0	0	0	0	1
J: Disposal	0	0	0	0	0	1
Total High-Speed Passenger Rail Transportation System EMERGY					1.29×10^{21}	1

The summarized comments for Table 8 aggregated EMERGY inputs for Alternative 1 (high-speed passenger rail) are as follows with the total phase EMERGY inputs ranked from highest to lowest.

1. Component production phase E
2. Material transformity phases A–C
3. Construction phase F
4. Use phase G

There were no EMERGY input sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of similar complexity and, as such, assumed equivalent for this analysis.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the use phase and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the disposal phase was zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

Table 9 contains the aggregated EMERGY input values for Alternative 2 (interstate passenger car). As with Table 8, the EMERGY values are calculated for the four external inputs over 10 phases. The total for each phase is summed to provide the total EMERGY for this alternative.

Table 9

Aggregated EMERGY Input – Alternative-2 (Interstate Passenger Car)

	EMERGY Input Source Data (sej)				Total Phase	
EVE Phase	Env. (E)	Fuel (F)	Goods (G)	Services (S)	EMERGY	MANOVA
A-C: Transformity	1.74×10^{20}	2.45×10^{19}	2.45×10^{19}	2.45×10^{19}	2.45×10^{20}	2
D: Design	0	0	0	0	0	2
E: Comp. Prod.	0	0	0	0	0	2
F: Const.	4.01×10^{15}	1.09×10^{18}	1.23×10^{17}	1.73×10^{18}	2.94×10^{18}	2
G: Use	2.43×10^{15}	8.11×10^{17}	5.43×10^{16}	7.83×10^{17}	1.65×10^{18}	2
H: Demolition	0	0	0	0	0	2
I: Recycling	0	0	0	0	0	2
J: Disposal	0	0	0	0	0	2
Total Interstate Passenger Car Transportation System EMERGY					2.52×10^{20}	2

The comments for Table 9 Aggregated EMERGY Inputs for Alternative 2 (interstate passenger car) are summarized by the following observations with the total phase EMERGY inputs ranked from highest to lowest.

1. Material transformity Phases A-C
2. Construction Phase F
3. Use Phase G

There were no EMERGY input sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of similar complexity and, as such, assumed equivalent for this analysis.

Component Production Phase E: The EMERGY associated with this phase was zero because component production occurred during the Use Phase.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not occur.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the Use Phase and the Demolition Phase did not occur.

Composite EMERGY Table Analysis

The Composite Phased EMERGY values by group tables show a comparative summary for the four inputs of environment, fuel energy, goods, and services. The composite EMERGY analysis tables were constructed by compiling the EMERGY associated with each transformity phase for high-speed passenger rail Alternative 1 and compiling the EMERGY associated with each phase for the interstate passenger car transportation Alternative 2. The respective columns were totaled to obtain the sum of EMERGY associated with all phases for the four areas of input consisting of environment, fuel energy, goods, and services. The data are presented in tables as indicated below.

- Table 10 shows the composite EMERGY values for environment by phase.
- Table 11 shows the composite EMERGY values for fuel energy by phase.
- Table 12 shows the composite EMERGY values for goods by phase.
- Table 13 shows the composite EMERGY values for services by phase.

Following the presentation of data in the tables, the results of each are summarized by evaluating the EMERGY values for the associated EVE phases over the four input categories. Data presented in this form facilitates an analysis of individual EMERGY inputs per phase and emphasizes areas of similarities as well as areas of differences in terms of impacts to the environment.

Table 10

Composite Phased EMERGY for Environment (E)

EVE Phase	Total Source Phase EMERGY (sej) Alternative 1	Total Source Phase EMERGY (sej) Alternative 2
A-C: Transformity	4.44×10^{19}	1.74×10^{20}
D: Design	0	0
E: Comp. Prod	8.52×10^{20}	0
F: Construction	1.06×10^{15}	4.01×10^{15}
G: Use	1.66×10^{13}	2.43×10^{15}
H: Demolition	0	0
I: Recycling	0	0
J: Disposal	0	0
Total	8.96×10^{20}	1.74×10^{20}

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

The comments for Table 10 composite EMERGY values for environment were summarized for high-speed passenger rail Alternative 1 with the total source phase EMERGY results ranked from highest to lowest.

1. Component Production Phase E
2. Material Transformity Phases A-C
3. Construction Phase F
4. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design Phase D: The assumption that the Design Phase for the high-speed passenger rail and interstate passenger car transportation alternatives were both of similar complexity and, as such, assumed equivalent for this analysis.

Demolition Phase H: The EMERGY associated with the Demolition Phase was not calculated separately given the fact that the demolition occurred in the Use Phase and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the use phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the use phase and the Demolition Phase did not take place.

The comments for Table 10 composite EMERGY values for environment were summarized for interstate passenger car Alternative 2 with the total source phase EMERGY results ranked from highest to lowest.

1. Material Transformity Phases A-C
2. Construction Phase F
3. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of similar complexity and, as such, assumed equivalent for this analysis.

Component Production Phase E: The EMERGY associated with this phase was zero because Component Production occurred during the Use Phase.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase, and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase were zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

Table 11

Composite Phased EMERGY Values for Fuel Energy (F)

EVE Phase	Total Source Phase EMERGY (sej) Alternative 1	Total Source Phase EMERGY (sej) Alternative 2
A-C: Transformity	6.00×10^{18}	2.45×10^{19}
D: Design	0	0
E: Comp. Prod.	1.22×10^{20}	0
F: Construction	9.50×10^{17}	1.09×10^{18}
G: Use	3.33×10^{17}	8.11×10^{17}
H: Demolition	0	0
I: Recycling	0	0
J: Disposal	0	0
Total	1.29×10^{20}	2.64×10^{19}

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

The following are summarized comments for Table 11 composite EMERGY values for fuel energy for high-speed passenger rail Alternative 1. When the total source phase EMERGY results were ranked from highest to lowest, the results are as follows:

1. Component Production Phase E
2. Material Transformity Phases A-C
3. Construction Phase F
4. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of similar complexity and, as such, assumed equivalent for this analysis.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase, and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

Interstate Passenger Car Transportation Alternative 2

When the total source phase EMERGY values in Table 11 for Alternative 2 (interstate passenger car) were ranked from highest to lowest, the results were as follows:

1. Material Transformity Phases A-C
2. Construction Phase F
3. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of similar complexity and, as such, assumed equivalent for this analysis.

Component Production Phase E: The EMERGY associated with this phase was zero because no component production occurred.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase, and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

Table 12

Composite Phased EMERGY Values for Goods (G)

EVE Phase	Total Source Phase EMERGY (sej) Alternative 1	Total Source Phase EMERGY (sej) Alternative 2
A-C: Transformity	6.00×10^{18}	2.45×10^{19}
D: Design	0	0
E: Comp. Prod.	1.22×10^{20}	0
F: Construction	3.13×10^{17}	1.23×10^{17}
G: Use	2.26×10^{16}	5.43×10^{16}
H: Demolition	0	0
I: Recycling	0	0
J: Disposal	0	0
Total	1.28×10^{20}	2.47×10^{19}

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

The following are summarized comments for High-Speed Passenger Rail Alternative 1 for Table 12 composite EMERGY values for goods. When the total source phase EMERGY results were ranked from highest to lowest, the results are as follows:

1. Component Production Phase E
2. Material Transformity Phases A-C
3. Construction Phase F
4. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of above average complexity and, as such, assumed equivalent for this analysis.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase, and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

Interstate Passenger Car Transportation Alternative 2, Table 12.

When the total source phase EMERGY results were ranked from highest to lowest, the results are as follows:

1. Material Transformity Phases A-C
2. Construction Phase F
3. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of similar complexity and, as such, assumed equivalent for this analysis.

Component Production Phase E: The EMERGY associated with this phase was zero because no component production occurred.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase, and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

Table 13

Composite Phased EMERGY Values for Services (S)

EVE Phase	Total Source Phase EMERGY (sej) Alternative 1	Total Source Phase EMERGY (sej) Alternative 2
A-C: Transformity	6.00×10^{18}	2.45×10^{19}
D: Design	0	0
E: Comp. Prod.	1.22×10^{20}	0
F: Construction	4.97×10^{18}	1.73×10^{18}
G: Use	9.25×10^{16}	7.83×10^{17}
H: Demolition	0	0
I: Recycling	0	0
J: Disposal	0	0
Total	1.33×10^{20}	2.70×10^{19}

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

The following are summarized comments for High-Speed Passenger Rail Alternative 1 for Table 13 composite EMERGY values for services. When the total source phase EMERGY results were ranked from highest to lowest, the results are as follows:

1. Component Production Phase E
2. Material Transformity Phases A-C
3. Construction Phase F
4. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design Phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of above average complexity and, as such, assumed equivalent for this analysis.

Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase, and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the Recycling Phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

When the total source phase EMERGY results were ranked from highest to lowest for the Interstate Passenger Car Transportation Alternative 2 Table 13, the results are as follows:

1. Material Transformity Phases A-C
2. Construction Phase F
3. Use Phase G

There were no EMERGY sources for the following phases as outlined below:

Design phase D: The assumption that the design for the high-speed passenger rail and interstate passenger car transportation alternatives were both of above average complexity and, as such, assumed equivalent for this analysis.

Component Production Phase E: The EMERGY associated with this phase was zero because no component production occurred.

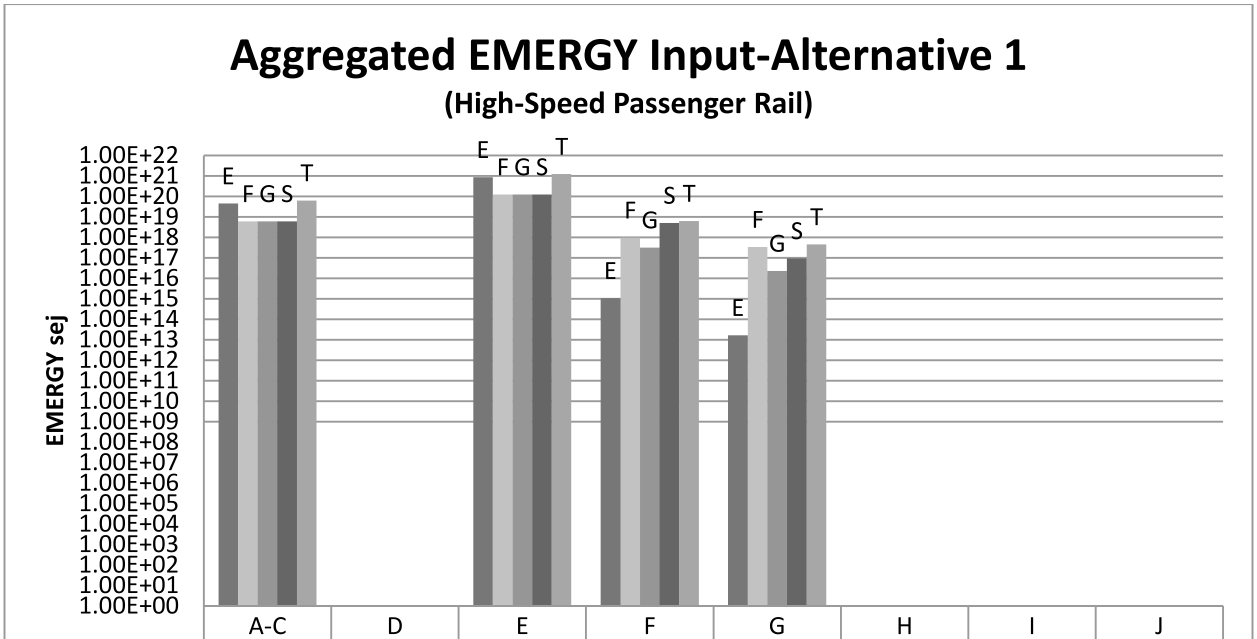
Demolition Phase H: The EMERGY associated with demolition was not calculated separately given the fact that the demolition occurred in the Use Phase, and the project scope did not consist of demolition at the end of this evaluation period.

Recycling Phase I: The EMERGY associated with the recycling phase was zero because the recyclable material was removed during the Use Phase and the Demolition Phase did not take place.

Disposal Phase J: The EMERGY associated with the Disposal Phase was zero because disposal was included in the Use Phase and the Demolition Phase did not take place.

Aggregated Phase EMERGY Input Signatures

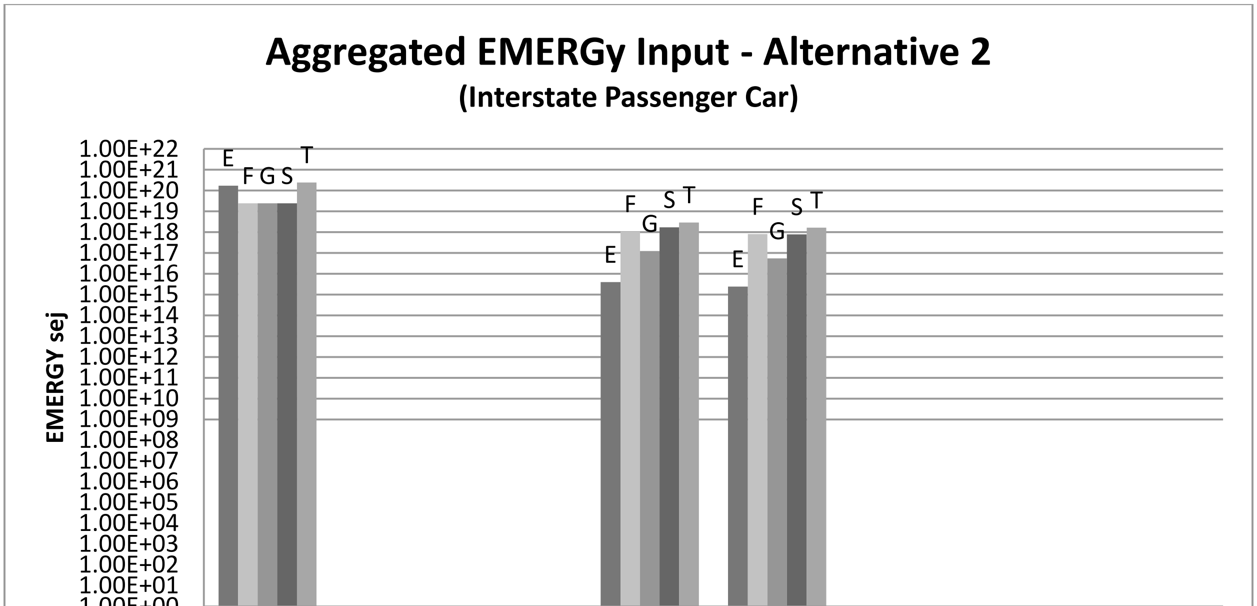
By converting the data in Tables 8 and 9 into chart form, one can view the aggregated EMERGY input signature which is a representation of the total EMERGY input for the transportation alternatives. Figure 6 presents the aggregated EMERGY input for the high-speed passenger rail Alternative 1 and Figure 7 reflects the aggregated EMERGY input for the interstate passenger car Alternative 2. The input categories are indicated as environment (E), fuel energy (F), goods (G), services (S) and total (T) for EVE phases A-J.



	A-C	D	E	F	G	H	I	J
E	4.44E+19	0	8.52E+20	1.06E+15	1.66E+13	0	0	0
F	6.00E+18	0	1.22E+20	9.50E+17	3.33E+17	0	0	0
G	6.00E+18	0	1.22E+20	3.13E+17	2.26E+16	0	0	0
S	6.00E+18	0	1.22E+20	4.97E+18	9.25E+16	0	0	0
T	6.24E+19	0	1.22E+21	6.23E+18	4.48E+17	0.00E+00	0.00E+00	0.00E+00

Figure 6. Aggregated EMERGY Input Alternative 1 (High-Speed Passenger Rail)

A review of Figure 6, Aggregated EMERGY input for Alternative 1 (high-speed passenger rail) indicates that the inputs of F, G, and S were equally clustered in the Transformity Phases A-C and the Component Production Phase E. The EMERGY values for the Construction (F) and Use (G) Phases indicate that the EMERGY for the environment shows less EMERGY than the inputs of F, G, and S. There were no EMERGY inputs for design, demolition, recycling or disposal for reasons noted previously.



	A-C	D	E	F	G	H	I	J
E	1.74E+20	0	0	4.01E+15	2.43E+15	0	0	0
F	2.45E+19	0	0	1.09E+18	8.11E+17	0	0	0
G	2.45E+19	0	0	1.23E+17	5.43E+16	0	0	0
S	2.45E+19	0	0	1.73E+18	7.83E+17	0	0	0
T	2.47E+20	0	0	2.94E+18	1.65E+18	0.00E+00	0.00E+00	0.00E+00

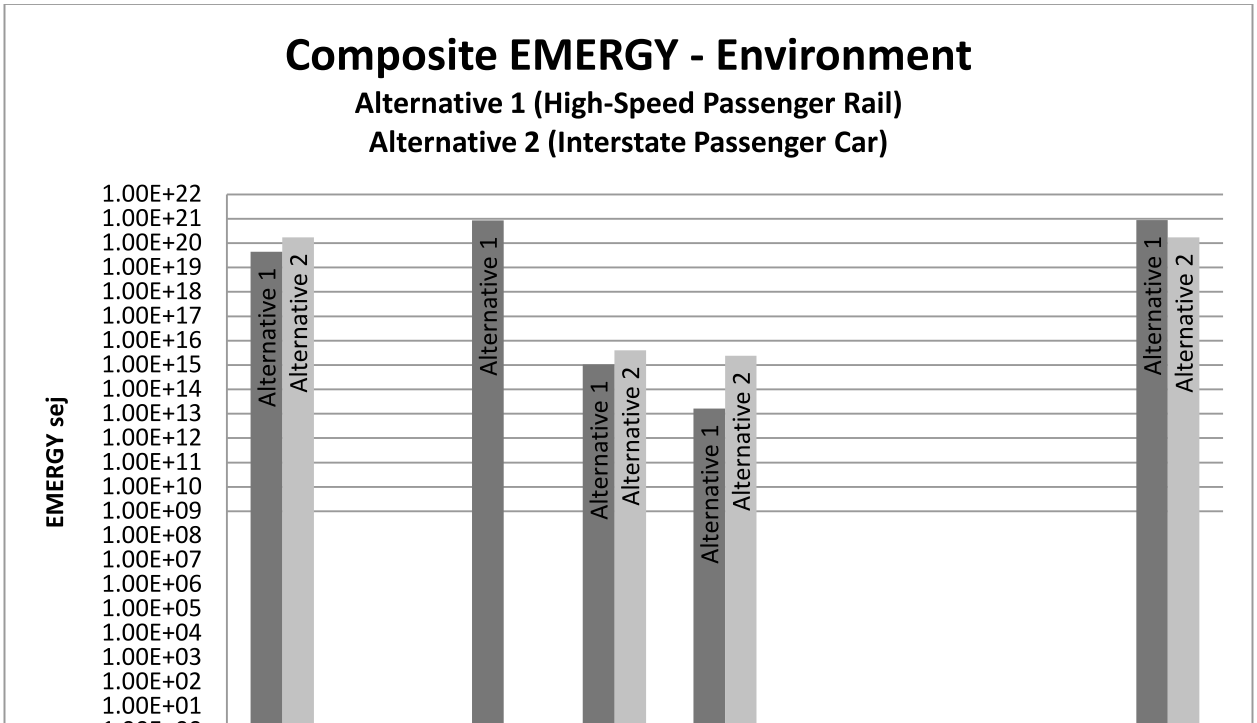
Figure 7. Aggregated EMERGY Input Alternative 2 (Interstate Passenger Car)

A review of Figure 7, Aggregated EMERGY input for Alternative 2 (interstate passenger car) indicates that the EMERGY inputs of F, G, and S are highly clustered for the Transformity Phases A-C relative to the EMERGY inputs for the Construction (F) and Use (G) Phases. It is noted that there were no EMERGY inputs for design, component production, demolition, recycling, or disposal for reasons noted previously.

Composite EMERGY Input Signatures

The composite EMERGY values by alternative were compiled to facilitate conducting an analysis to further evaluate where a difference in EMERGY existed between the two transportation alternatives. The following charts were compiled from Tables 10, 11, 12 and 13 respectively. Refer to the following figures for composite EMERGY analysis for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives.

- Figure 8 for composite EMERGY values for environment
- Figure 9 for composite EMERGY values for fuel energy
- Figure 10 for composite EMERGY values for goods
- Figure 11 for composite EMERGY values for services



	A-C	D	E	F	G	H	I	J	Total
Alternative 1	4.44E+19	0	8.52E+20	1.06E+15	1.66E+13	0	0	0	8.96E+20
Alternative 2	1.74E+20	0	0	4.01E+15	2.43E+15	0	0.00E+00	0	1.74E+20

Figure 8. Composite EMERGY - Environment

A review of Figure 8, the composite EMERGY of Environment for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) indicated the following:

Transformity Phases A-C: The EMERGY input for Alternative 2 (interstate passenger car) was higher than the EMERGY input for Alternative 1 (high-speed passenger rail).

Design Phase D: There were no EMERGY inputs from either group.

Component Production Phase E: There were EMERGY inputs from Alternative 1 (high-speed passenger rail) but no EMERGY inputs from Alternative 2 (interstate passenger car).

Construction Phase F: The EMERGY inputs for Alternative 2 (interstate passenger car) were higher than the EMERGY inputs for Alternative 1 (high-speed passenger rail).

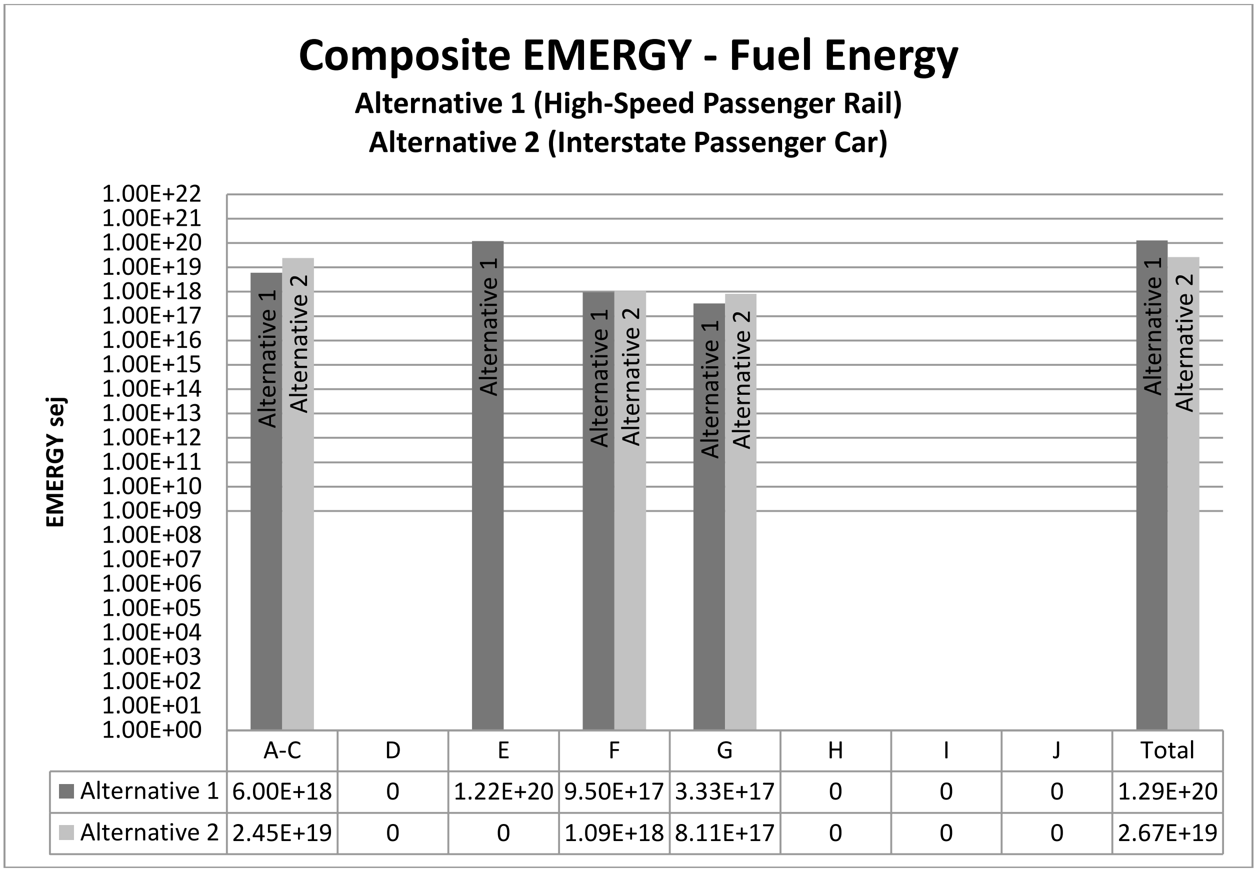
Use Phase G: EMERGY inputs for Alternative 2 (interstate passenger car) were higher than the EMERGY inputs for Alternative 1 (high-speed passenger rail).

Demolition Phase H: There were no EMERGY inputs for either alternative.

Recycling Phase I: There were no EMERGY inputs for either alternative.

Disposal Phase J: There were no EMERGY inputs for either alternative.

Total EMERGY: The total EMERGY for environment was higher for Alternative 1 (high-speed passenger rail).



	A-C	D	E	F	G	H	I	J	Total
Alternative 1	6.00E+18	0	1.22E+20	9.50E+17	3.33E+17	0	0	0	1.29E+20
Alternative 2	2.45E+19	0	0	1.09E+18	8.11E+17	0	0	0	2.67E+19

Figure 9. Composite EMERGY - Fuel Energy

A review of Figure 9, Composite EMERGY of Fuel Energy for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives indicated the following:

Transformity Phases A-C: The EMERGY input for Alternative 2 (interstate passenger car) was higher than the EMERGY input for Alternative 1 (high-speed passenger rail).

Design Phase D: There were no EMERGY inputs from either alternative.

Component Production Phase-E: There were EMERGY inputs from Alternative 1 (high-speed passenger rail) but no EMERGY inputs from Alternative 2 (interstate passenger car).

Construction Phase F: The EMERGY inputs for Alternative 2 (interstate passenger car) were higher than Alternative 1 (high-speed passenger rail).

Use Phase G: EMERGY inputs for Alternative 2 (interstate passenger car) were higher than Alternative 1 (high-speed passenger rail).

Demolition Phase H: There are no EMERGY inputs for either alternative.

Recycling Phase I: There were no EMERGY inputs for either alternative.

Disposal Phase J: There are no EMERGY inputs for either alternative.

Total EMERGY: The total EMERGY for Fuel Energy was higher for alternative 1 (high-speed passenger rail).

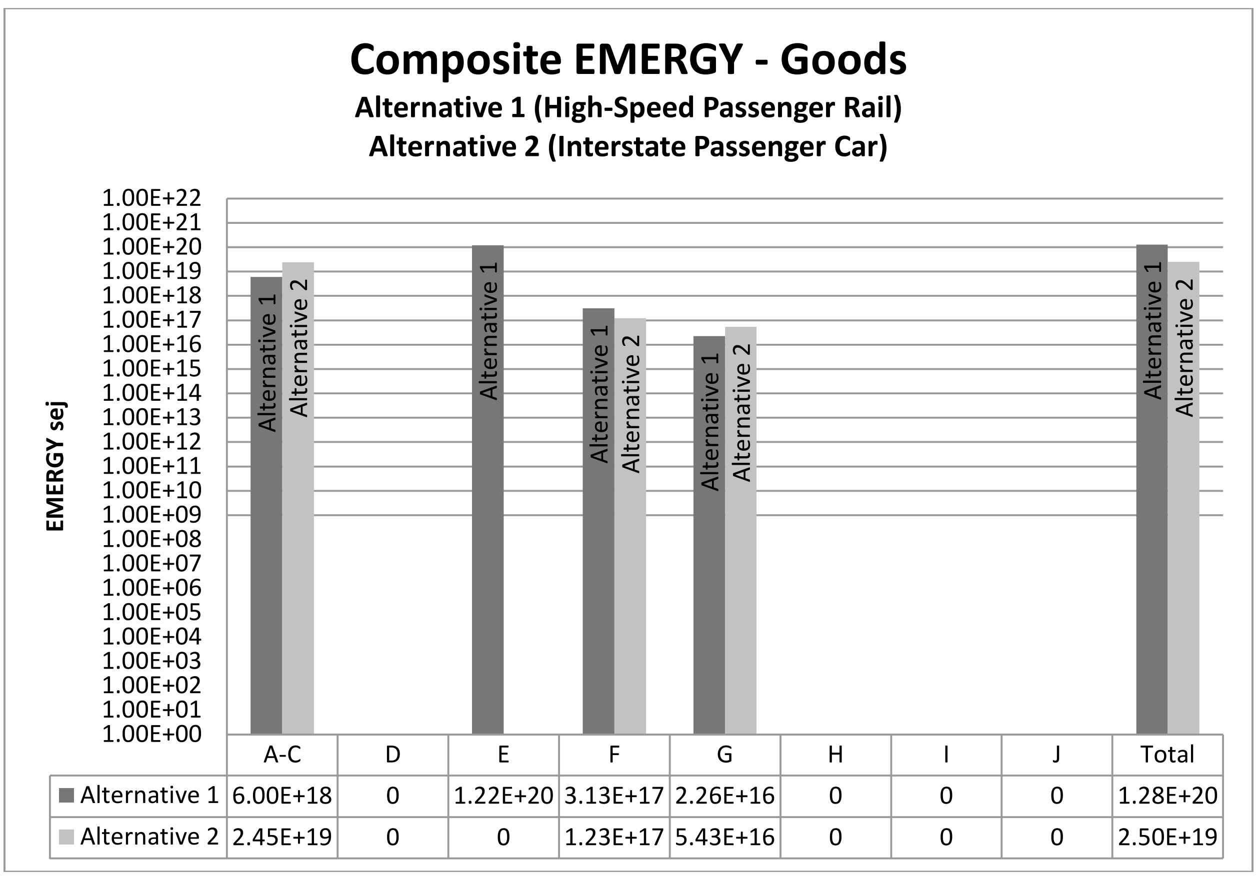


Figure 10. Composite EMERGY - Goods

A review of Figure 10, Composite EMERGY of Goods for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives indicated the following:

Transformity Phase A-C: The EMERGY input for Alternative 2 (interstate passenger car) was higher than the EMERGY input for Alternative 1 (high-speed passenger rail).

Design Phase D: There were no EMERGY inputs from either alternative.

Component Production Phase E: There were EMERGY inputs from Alternative 1 (high-speed passenger rail) but no EMERGY inputs from Alternative 2 (interstate passenger car).

Construction Phase F: The EMERGY inputs for Alternative 1 (high-speed passenger rail) were higher than Alternative 2 (interstate passenger car).

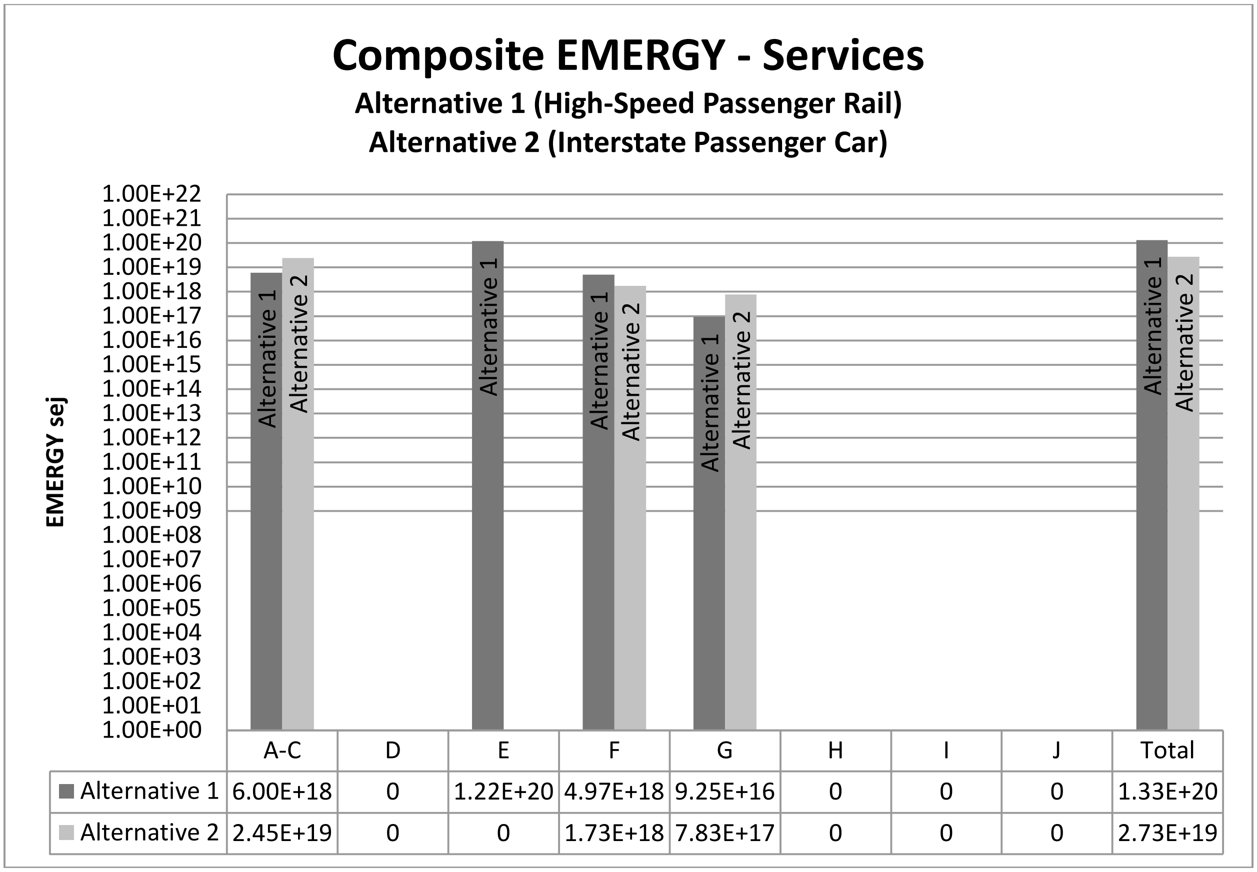
Use Phase G: EMERGY inputs for Alternative 2 (interstate passenger car) were higher than Alternative 1 (high-speed passenger rail).

Demolition Phase H: There were no EMERGY inputs for either alternative.

Recycling Phase I: There were no EMERGY inputs for either alternative.

Disposal Phase J: There are no EMERGY inputs for either alternative.

Total EMERGY: The total EMERGY for goods is higher for Alternative 1 (high-speed passenger rail).



	A-C	D	E	F	G	H	I	J	Total
Alternative 1	6.00E+18	0	1.22E+20	4.97E+18	9.25E+16	0	0	0	1.33E+20
Alternative 2	2.45E+19	0	0	1.73E+18	7.83E+17	0	0	0	2.73E+19

Figure 11. Composite Phase EMERGY - Services

A review of Figure 11, Composite EMERGY of services for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) indicated the following:

Transformity Phases A-C: The EMERGY input for Alternative 2 (interstate passenger car) was higher than the EMERGY input for Alternative 1 (high-speed passenger rail).

Design Phase D: There were no EMERGY inputs from either alternative.

Component Production Phase-E: There were EMERGY inputs from Alternative 1 (high-speed passenger rail) but no EMERGY inputs from Alternative 2 (interstate passenger car).

Construction Phase F: EMERGY input for Alternative 1 (high-speed passenger rail) was higher than Alternative 2 (interstate passenger car).

Use Phase G: The EMERGY input for Alternative 2 (interstate passenger car) was higher than Alternative 1 (high-speed passenger rail).

Demolition Phase H: There were no EMERGY inputs for either alternative.

Recycling Phase I: There were no EMERGY inputs for either alternative.

Disposal Phase J: There were no EMERGY inputs for either alternative.

Total EMERGY: The total EMERGY for goods was higher for Alternative 1 (high-speed passenger rail).

Comparison of Transportation Alternatives

An EVE EMERGY analysis rubric was conducted to compare high-speed passenger rail and interstate passenger car transportation alternatives through a fixed distance. The following table compares the total EMERGY values for environment, fuel energy, goods, and services over the 10 life cycle phases for both alternatives. Table 14 presents the total phased EMERGY input by alternative.

Table 14

Total Phased EMERGY Input by Alternative

EVE Phase	Total Source Phase EMERGY (sej) Alternative 1	Total Source Phase EMERGY (sej) Alternative 2
A-C: Transformity	6.24×10^{19}	2.47×10^{20}
D: Design	0	0
E: Comp. Prod.	1.22×10^{21}	0
F: Construction	6.23×10^{18}	2.94×10^{18}
G: Use	4.48×10^{17}	1.65×10^{18}
H: Demolition	0	0
I: Recycling	0	0
J: Disposal	0	0
Total	1.29×10^{21}	2.52×10^{20}

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

A graph was prepared from the data contained in Table 14 to facilitate a visual analysis of the comparison of the total EMERGY. Figure 12 contains the resulting output.

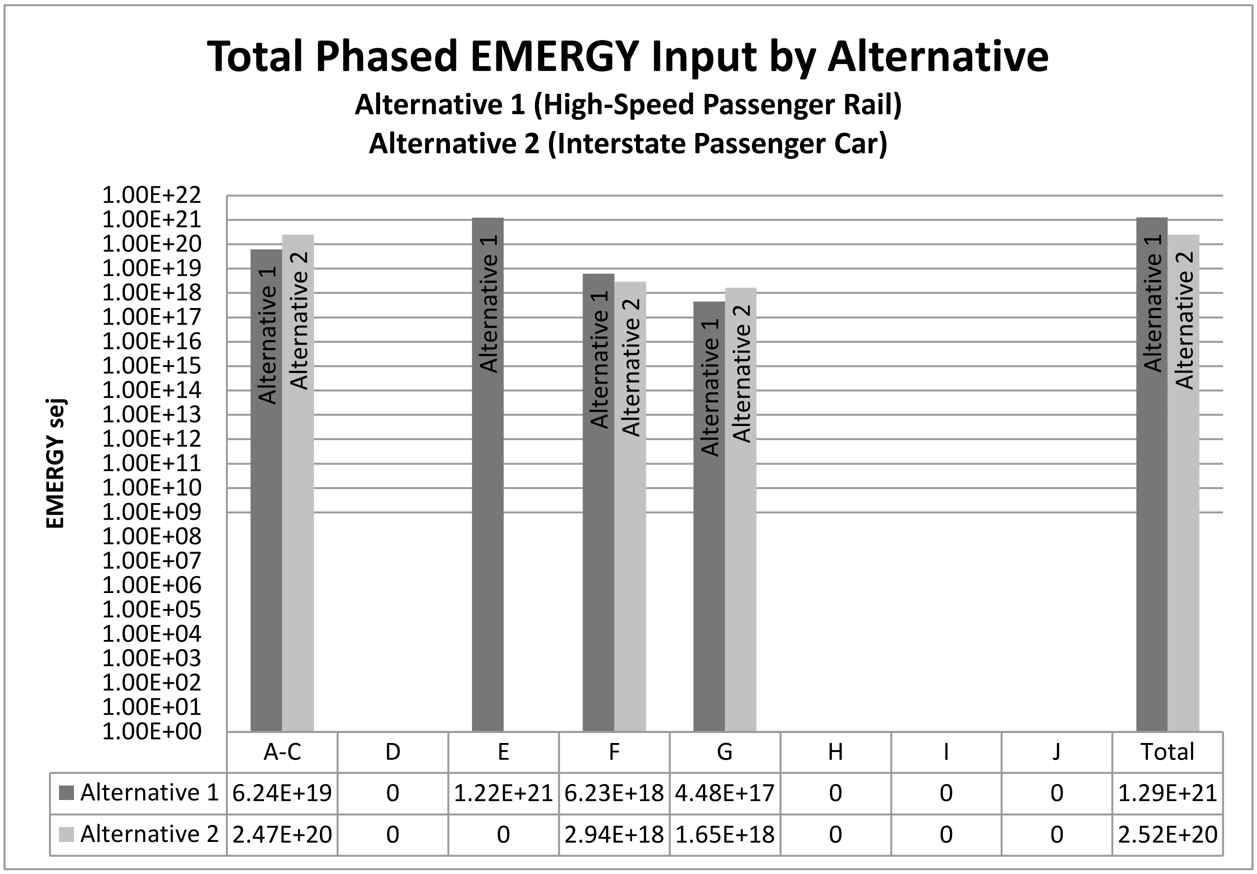


Figure 12. Total Phased EMERGY Input by Alternative.

A review of Figure 12, Total Phased EMERGY Input by Alternative indicated the following for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car):

Transformity Phases A-C: The EMERGY input for Alternative 2 (interstate passenger car) was higher than the EMERGY input for Alternative 1 (high-speed passenger rail).

Design Phase D: There were no EMERGY inputs from either group.

Component Production Phase E: There were EMERGY inputs from Alternative 1 (high-speed passenger rail) but no EMERGY inputs from Alternative 2 (interstate passenger car).

Construction Phase F: The EMERGY input for Alternative 1 (high-speed passenger rail) was higher than Alternative 2 (interstate passenger car).

Use Phase G: The EMERGY input for Alternative 2 (interstate passenger car) was higher than Alternative 1 (high-speed passenger rail).

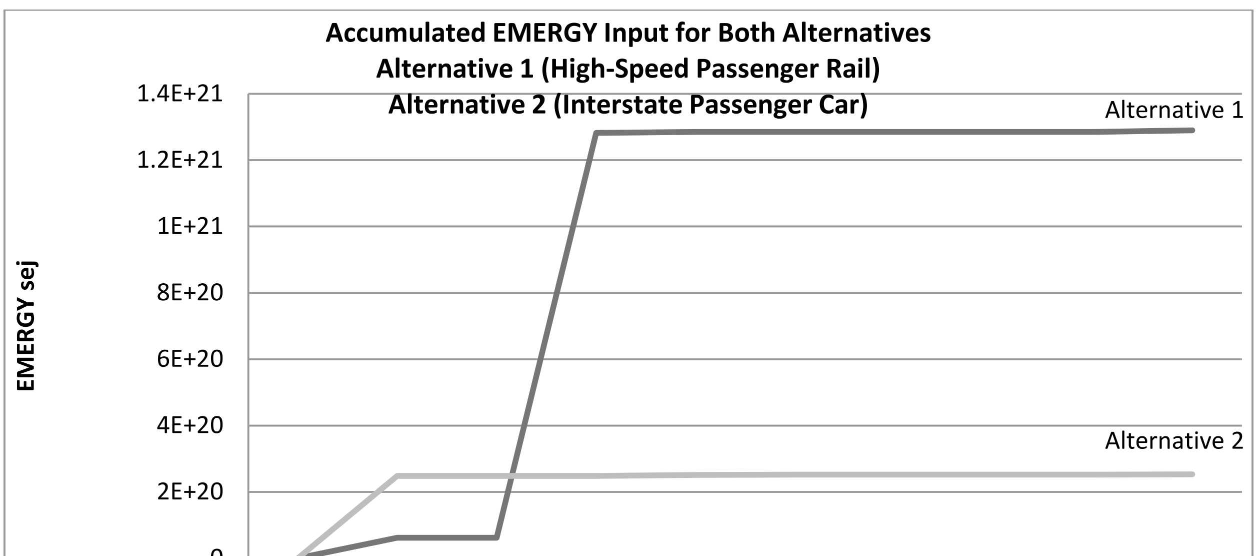
Demolition Phase H: There were no EMERGY inputs for either alternative.

Recycling Phase I: There were no EMERGY inputs for either alternative.

Disposal Phase J: There were no EMERGY inputs for either alternative.

Total EMERGY: The total EMERGY was higher for Alternative 1 (high-speed passenger rail) than Alternative 2 (interstate passenger car) by a factor of approximately 5.

To further enhance the ability to analyze the total EMERGY Input by Alternative, Figure 13 was developed to track accumulated EMERGY over the 10 phases consisting of inputs of environment, fuel energy, goods, and services.



		A-C	D	E	F	G	H	I	J	Total
Alternative 1	0	6.2E+19	6.2E+19	1.3E+21	1.3E+21	1.3E+21	1.3E+21	1.3E+21	1.3E+21	1.3E+21
Alternative 2	0	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20

Figure 13. Accumulated EMERGY Input for Both Alternatives.

The summarized comments for Figure 13 Accumulated EMERGY input for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives are as follows:

The highest EMERGY use occurred during the Component Production Phase for Alternative 1 (high-speed passenger rail) and during the Transformity Phase for Alternative 2 (interstate passenger car).

The total EMERGY for Alternative 1 (high-speed passenger rail) was approximately five times greater than the total EMERGY for Alternative 2 (interstate passenger car).

EMERGY per Passenger Mile

In an effort to calculate the EMERGY per passenger mile for each transportation alternative, the information outlined in Limitations 6 and 7 were evaluated further. Limitation 6 provided information that showed a 1,216 passenger capacity in a 12 hour period for the high-speed rail alternative used in this analysis. Limitation 7 indicated that a section of the interstate could transport 49,753 passengers in a 24 hour time period or 24,876.5 passengers in a 12 hour period. A review of the calculations for EMERGY per passenger mile indicates that Alternative 1 (high-speed passenger rail) uses more EMERGY per passenger mile than Alternative 2 (interstate passenger car) by a factor of ~ 104.95.

Alternative 1 High-speed rail EMERGY per passenger mile:

$$= (1.29x10^{21} sej)/(1{,}216\ passengers)(1\ mile)$$

$$= 1.06x10^{18} sej/passenger\ mile$$

Alternative 2 Interstate passenger car transportation EMERGY per passenger mile:

$$= (2.52x10^{20} sej)/(24{,}876.5\ passengers)(1\ mile)$$

$$= 1.01x10^{16} sej/passenger\ mile$$

Statistical Analysis

IBM SPSS statistics software was used to conduct a multivariate analysis of variance (MANOVA) to evaluate the Aggregated EMERGY Inputs for both alternatives to determine if a significant difference existed between the results. Field (2013) stated that a MANOVA can be used to evaluate multiple dependent and independent variables simultaneously. Tables 15 through 29 and Figures 14 through 21 reflect the SPSS MANOVA results. An analysis of the data is provided after the tables and figures.

H_0: The null hypothesis stated that there was no difference in terms of environmental impacts to natural resources between high-speed passenger rail and interstate passenger car transportation alternatives.

H_a: The alternative hypothesis stated that there was a difference in terms of environmental impacts to natural resources between high-speed passenger rail and interstate passenger car transportation alternatives.

Refer to Table 15 for the SPSS descriptive statistics calculations. Although the samples in this report were small, it was beneficial to analyze the normality of the data based on the descriptive statistics.

Table 15

Descriptive Statistics

	Environment	Fuel	Goods	Services
N (Valid)	16	16	16	16
Missing	0	0	0	0
Mean	6.6900E+019	9.7302E+018	9.5633E+018	1.0005E+019
Median	0.0000E+000	0.0000E+000	0.0000E+000	0.0000E+000
Mode	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Skewness	3.745	3.757	3.754	3.752
Std. Error of Skewness	.564	.564	.564	.564
Kurtosis	14.380	14.459	14.440	14.440
Std. Error of Kurtosis	1.091	1.091	1.091	1.091

An analysis of the data in Table 15 indicates the following:

a. The results showed the calculated values for mean, median, and mode. This data were utilized to review central tendency.

b. Skewness was positive so the data collected to the left and the tail pointed to the right. In a normal distribution, skewness is zero; this data had a skewness of approximately 3.7 for the four inputs of environment, fuel energy, goods, and services.

c. Kurtosis results indicated that this data was distributed in a very tall and narrow output. In a normal distribution, kurtosis is zero; this data had an average kurtosis value of 14.4 for the four inputs of environment, fuel energy, goods, and services.

Refer to Tables 16-19 for the frequency distribution analysis to observe how often a result occurred. A review of the frequency distributions for environment, fuel energy, goods, and services indicated that of the 16 entries, zero was the most frequently occurring number and each additional number occurred only once.

Table 16

Frequency - Environment

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0.00E+000	9	56.3	56.3	56.3
	1.66E+013	1	6.3	6.3	62.5
	1.06E+015	1	6.3	6.3	68.8
	2.43E+015	1	6.3	6.3	75.0
	4.01E+015	1	6.3	6.3	81.3
	4.44E+019	1	6.3	6.3	87.5
	1.74E+020	1	6.3	6.3	93.8
	8.52E+020	1	6.3	6.3	100.0
Total		16	100.0	100.0	

Table 17

Frequency - Fuel Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0.00E+000	9	56.3	56.3	56.3
	3.33E+017	1	6.3	6.3	62.5
	8.11E+017	1	6.3	6.3	68.8
	9.50E+017	1	6.3	6.3	75.0
	1.09E+018	1	6.3	6.3	81.3
	6.00E+018	1	6.3	6.3	87.5
	2.45E+019	1	6.3	6.3	93.8
	1.22E+020	1	6.3	6.3	100.0
Total		16	100.0	100.0	

Table 18

Frequency - Goods

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0.00E+000	9	56.3	56.3	56.3
	2.26E+016	1	6.3	6.3	62.5
	5.43E+016	1	6.3	6.3	68.8
	1.23E+017	1	6.3	6.3	75.0
	3.13E+017	1	6.3	6.3	81.3
	6.00E+018	1	6.3	6.3	87.5
	2.45E+019	1	6.3	6.3	93.8
	1.22E+020	1	6.3	6.3	100.0
Total		16	100.0	100.0	

Table 19

Frequency - Services

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0.00E+000	9	56.3	56.3	56.3
	9.25E+016	1	6.3	6.3	62.5
	7.83E+017	1	6.3	6.3	68.8
	1.73E+018	1	6.3	6.3	75.0
	4.97E+018	1	6.3	6.3	81.3
	6.00E+018	1	6.3	6.3	87.5
	2.45E+019	1	6.3	6.3	93.8
	1.22E+020	1	6.3	6.3	100.0
Total		16.0	100.0	100.0	

Refer to Figures 14-17. Histograms can be used to gain a visual perspective of the data distribution and are beneficial in evaluating if the data is normally distributed. The data for the four inputs of environment, fuel energy, goods, and services collected to the left and the tail pointed to the right. The results indicated that the data did not follow a normal distribution.

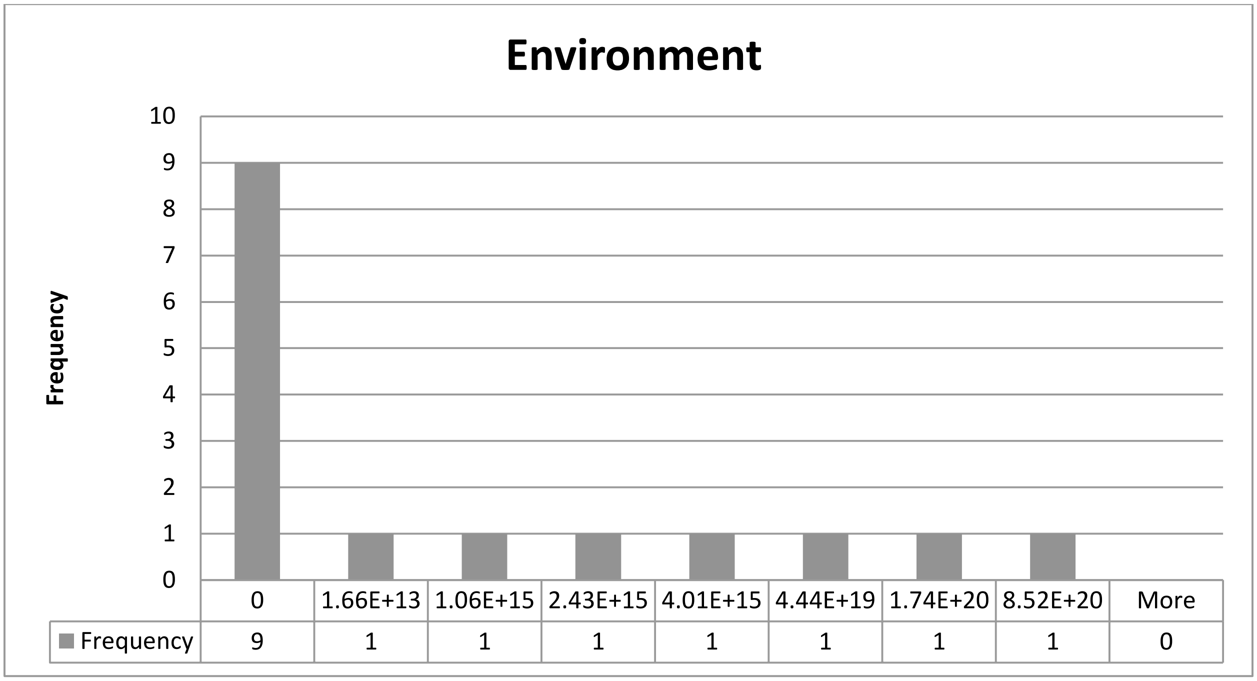


Figure 14. Histogram - Environment

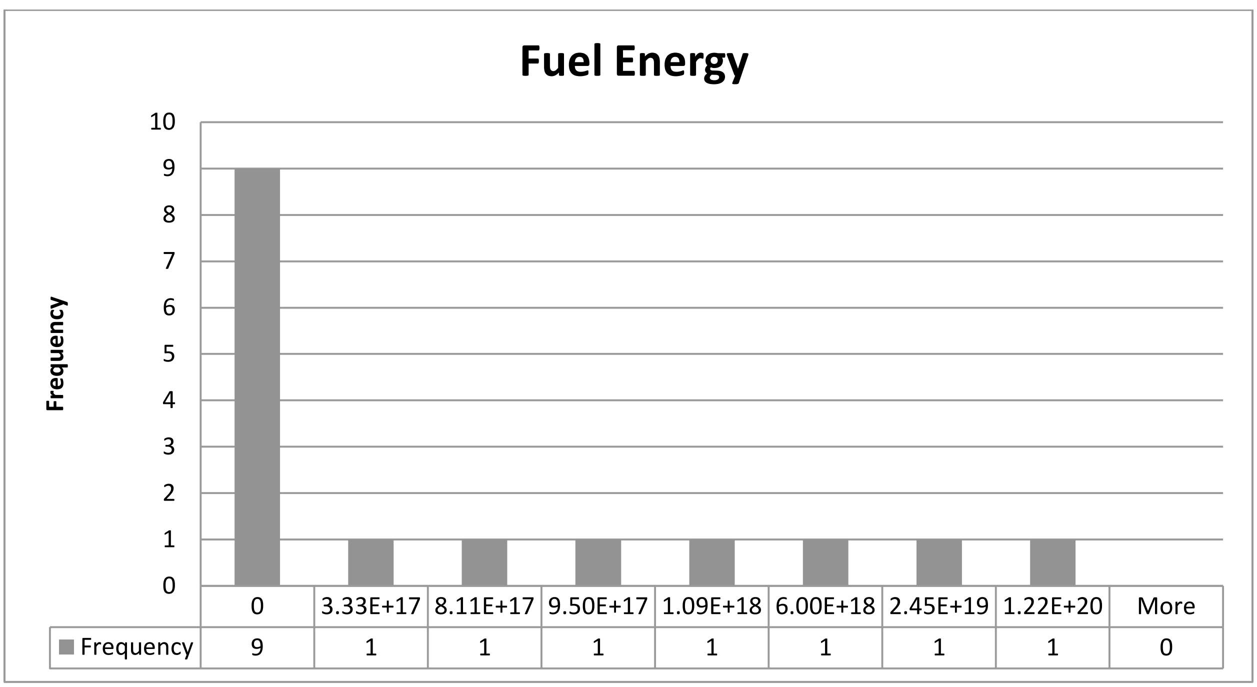


Figure 15. Histogram – Fuel energy

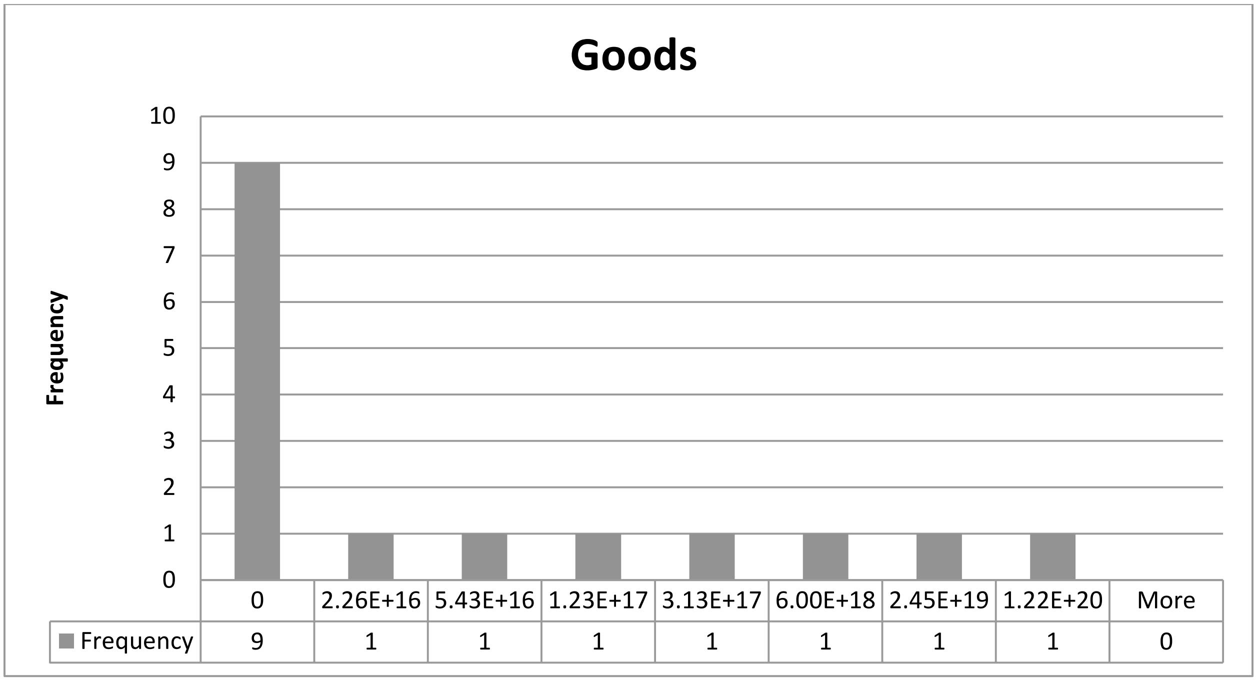


Figure 16. Histogram - Goods

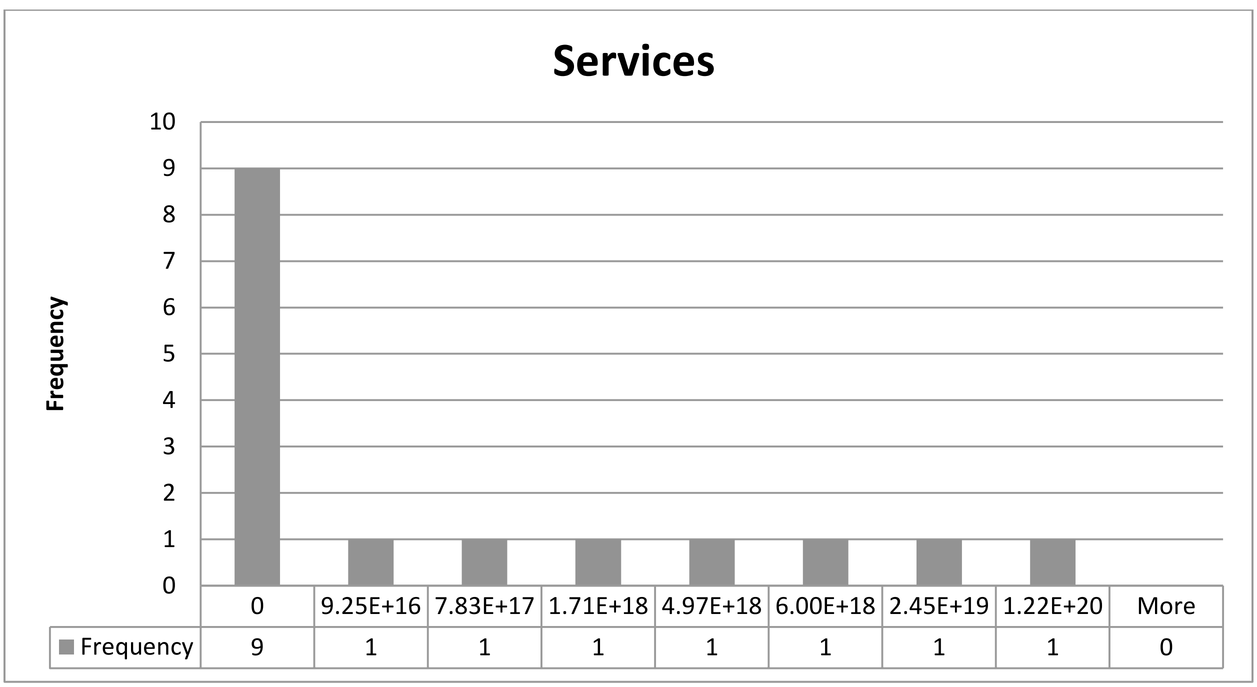


Figure 17. Histogram - Services

Table 20 Statistics shows the cumulative calculated values for mean, median, and mode for the four inputs of environment, fuel energy, goods, and services.

Table 20

Statistics

	Mean	Std. Deviation	*N*
Environmental	6.6900E+19	2.13938E+20	16
Fuel Energy	9.7302E+018	3.05595E+19	16
Goods	9.5633E+018	3.06127E+19	16
Services	1.0005E+018	3.04927E+19	16

Refer to Table 21 for the partial correlation between two variables while the other variables remain constant. A correlation value of one indicates a strong positive correlation among variables.

Table 21

Partial Correlation

	Control Variables		Environment	Fuel	Goods	Services
Alternative	Environment	Correlation	1.000	1.000	1.000	.999
		Significance (2-tailed)		.000	.000	.000
		df	0	13	13	13
	Fuel	Correlation	1.000	1.000	1.000	.999
		Significance (2-tailed)	.000		.000	.000
		df	13	0	13	13
	Goods	Correlation	1.000	1.000	1.000	.999
		Significance (2-tailed)	.000	.000		.000
		df	13	13	0	13
	Services	Correlation	.999	.999	.999	1.000
		Significance (2-tailed)	.000	.000	.000	
		df	13	13	13	0

A review of the data in Table 21 indicates a strong positive correlation among the four dependent variables of environment, fuel energy, goods and services. Table 22 shows the between subject factors for both alternatives and indicates the total number of samples per alternative. Table 23 shows the descriptive statistics for both alternatives.

Table 22

Between Subjects Factors

Alternative	*N*
1	8
2	8

Table 23

Additional Descriptive Statistics

	Alternative	Mean	Std. Deviation	*N*
Environment	1	1.1205E+020	2.99388E+20	8
	2	2.1751E+019	6.15180E+19	8
	Total	6.6900E+019	2.13938E+20	16
Fuel	1	1.6180E+019	4.28148E+19	8
	2	3.3001E+018	8.57712E+18	8
	Total	9.7302E+018	3.05595E+19	16
Goods	1	1.6042E+019	4.28641E+19	8
	2	3.0847E+018	8.65322E+18	8
	Total	9.5633E+018	3.06127E+19	16
Services	1	1.6633E+019	4.26472E+19	8
	2	3.3766E+018	8.55773E+18	8
	Total	1.0005E+019	3.04927E+19	16

General Linear Model Warnings: Box's Test of Equality of Covariance Matrices was not computed because there were fewer than two nonsingular cell covariance matrices. Post hoc tests were not performed for each alternative because there were fewer than three alternatives.

1. General Linear Model Tables 22 and 23 results are as follows:
    a. Since there were only two alternatives, SPSS did not run the Box's test of equality of covariance matrices.
    b. Since there were fewer than three alternatives, SPSS did not run any post hoc tests.
    c. A review of the between subject factors indicated that there were two alternatives each with eight dependent variables.

d. The descriptive statistics showed the mean and standard deviation of the four inputs for both alternatives

Refer to Tables 24 and 25, the multivariate tests showed four options for evaluating alternative significance.

Table 24

Multivariate Tests[a]

Effect	Test	Value	*F*	Hypothesis *df*	Error *df*	Sig.
Intercept	Pillai's Trace	.406	1.877[b]	4.000	11.000	.185
	Wilks' Lambda	.594	1.877[b]	4.000	11.000	.185
	Hotelling's Trace	.682	1.877[b]	4.000	11.000	.185
	Roy's Largest Root	.682	1.877[b]	4.000	11.000	.185
Alternative	Pillai's Trace	.168	.554[b]	4.000	11.000	.701
	Wilks' Lambda	.832	.554[b]	4.000	11.000	.701
	Hotelling's Trace	.201	.554[b]	4.000	11.000	.701
	Roy's Largest Root	.201	.554[b]	4.000	11.000	.701

Note. [a]Design: Intercept + Alternative; [b]Exact statistic; [c]Computed using alpha .05

Table 25

Additional Multivariate Tests

Effect	Test	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Intercept	Pillai's Trace	.406	7.507	.397
	Wilks' Lambda	.406	7.507	.397
	Hotelling's Trace	.406	7.507	.397
	Roy's Largest Root	.406	7.507	.397
Alternative	Pillai's Trace	.168	2.214	.137
	Wilks' Lambda	.168	2.214	.137
	Hotelling's Trace	.168	2.214	.137
	Roy's Largest Root	.168	2.214	.137

Note. [a]Design: Intercept = Group; [b]Exact statistic; [c]Computed using alpha = .05

A review of the data in Table 24 indicates the following: Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root all indicate that the significance was greater than alpha. As such, the null hypothesis could not be rejected based upon information presented and there was no indicated significant difference between Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car). A review of the data in Table 25 indicates that the partial eta squared was 0.406 for the intercept and 0.168 for the alternative. Partial eta squared relates to variable accountability. The observed power was 0.397 for the intercept and 0.137 for the alternative; this was less than an optimal value of 0.80.

Refer to Table 26, Levene's Tests of Equality, a review of this data showed that the significance was greater than the alpha value and, as such, the null hypothesis was not rejected but concluded that the error variance of the dependent variable was equal across alternatives.

Table 26

Levene's Tests of Equality of Error Variances[a]

	F	*df*1	*df*2	Sig.
Environment	3.280	1	14	.092
Fuel	3.334	1	14	.089
Goods	3.317	1	14	.090
Services	3.325	1	14	.090

Note. Tests the null hypothesis that the error variance of the dependent variable is equal across groups; [a]Design: Intercept + Group

Refer to Tables 27 and 28 where a review of the tests of between subjects' effects indicated that the significance was greater than the alpha value and, as such, the null hypothesis was not rejected. The partial eta squared was 0.047 to 0.108 and related to variable accountability. The observed power ranged from 0.122 to 0.228 which was less than an optimal value of 0.80.

Table 27

Tests of Between Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	*df*	Mean Square	*F*
Corrected Model	Environment	3.262E+040[a]	1	3.262E+040	.698
	Fuel	6.615E+038[b]	1	6.615E+038	.694
	Goods	6.716E+038[c]	1	6.716E+038	.702
	Services	7.029E+038[d]	1	7.029E+038	.743
Intercept	Environment	7.161E+040	1	7.161E+040	1.533
	Fuel	1.515E+039	1	1.515E+039	1.589
	Goods	1.463E+039	1	1.463E+039	1.530
	Services	1.602E+039	1	1.602E+039	1.693
Alternative	Environment	3.262E+040	1	3.262E+040	.698
	Fuel	6.615E+038	1	6.615E+038	.694
	Goods	6.716E+038	1	6.716E+038	.702
	Services	7.029E+038	1	7.029E+038	.743
Error	Environment	6.539E+041	14	4.671E+040	
	Fuel	1.335E+040	14	9.533E+038	
	Goods	1.339E+040	14	9.561E+038	
	Services	1.324E+040	14	9.460E+038	
Total	Environment	7.582E+041	16		
	Fuel	1.552E+040	16		
	Goods	1.552E+040	16		
	Services	1.555E+040	16		
Corrected Total	Environment	6.865E+041	15		
	Fuel	1.401E+040	15		
	Goods	1.406E+040	15		
	Services	1.395E+040	15		

Note. [a]*R* squared = .048 (Adjusted *R* squared = -.021);
[b]*R* squared = .047 (adjusted *R* squared = -.021);
[c]*R* squared = .048 (adjusted *R* squared = -.020);
[d]*R* squared = .050 (Adjusted R Squared = -.017)

Table 28

Additional Tests of Between Subjects Effects

Source	Dependent Variable	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[e]
Corrected Model	Environment	.417	.048	.698	.122
	Fuel	.419	.047	.694	.122
	Goods	.416	.048	.702	.122
	Services	.403	.050	.743	.127
Intercept	Environment	.236	.099	1.533	.211
	Fuel	.228	.102	1.589	.217
	Goods	.236	.099	1.530	.211
	Services	.214	.108	1.693	.228
Alternative	Environment	.417	.048	.698	.122
	Fuel	.419	.047	.694	.122
	Goods	.416	.048	.702	.122
	Services	.403	.050	.743	.127
Error	Environment				
	Fuel				
	Goods				
	Services				
Total	Environment				
	Fuel				
	Goods				
	Services				
Corrected Total	Environment				
	Fuel				
	Goods				
	Services				

Note. [a]*R* squared = .048 (adjusted *R* squared = -.021); [b]*R* squared = .047 (adjusted *R* squared = -.021); [c]*R* squared = .048 (adjusted *R* squared = -.020); [d]*R* squared = .050 (adjusted *R* squared = -.019); [e]Computed using alpha = .05

Refer to Table 29 for the estimated marginal means. This table depicts the marginal means for both transportation alternatives and the associated standard deviations for each value. Refer to Figures 18 through 21 for the subsequent profile plots for environment, fuel energy, goods and services for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) transportation alternatives. The estimated EMERGY of the marginal means in solar emjoules (sej) is shown on the vertical axis. The horizontal axis contains two rows of information. The first row identifies the transportation alternative while the second row depicts the numerical value of the respective marginal mean for that alternative. The presentation of data in this manner eliminates the need for the reader to interpret the marginal mean.

Table 29

Estimated Marginal Means

			95% Confidence Interval	
Dependent Variable	Alternative 1	Std. Deviation	Alternative 2	Std. Deviation
Environment	1.121E+20	2.994E+20	2.175E+19	6.152E+19
Fuel	1.616E+19	4.281E+19	3.300E+18	8.577E+18
Goods	1.604E+19	4.286E+19	3.085E+18	8.653E+18
Services	1.663E+19	4.264E+19	3.377E+18	8.558E+18

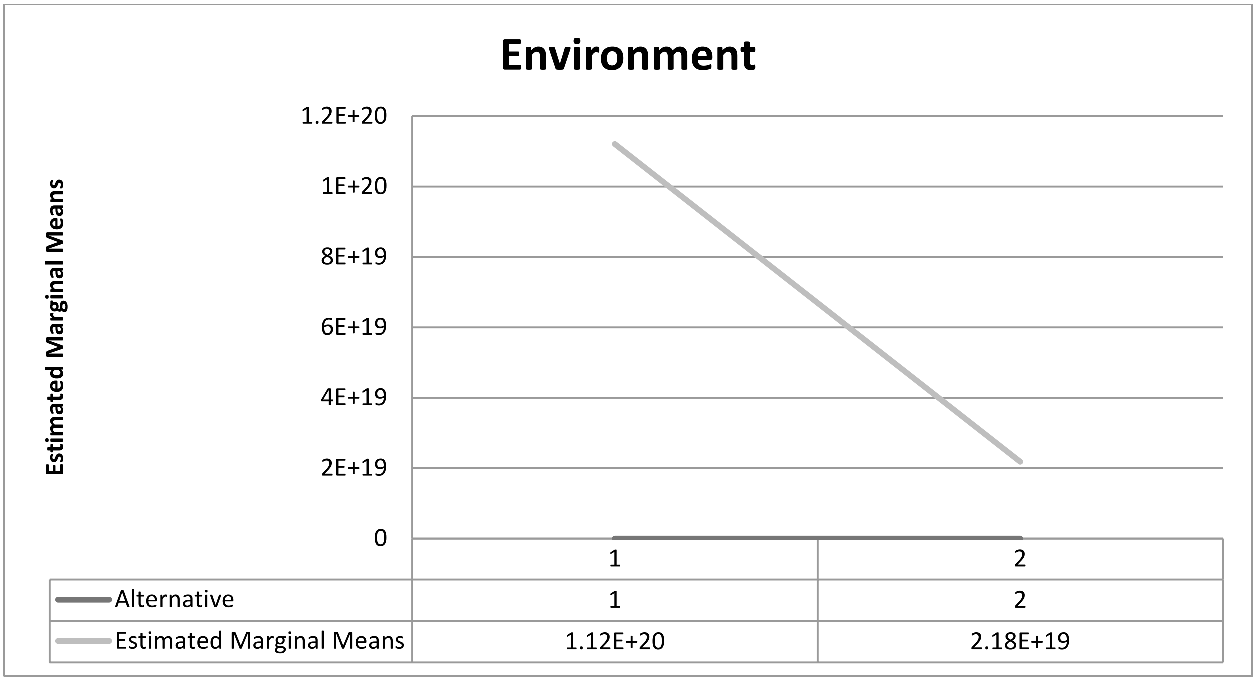


Figure 18. Profile Plot - Environment

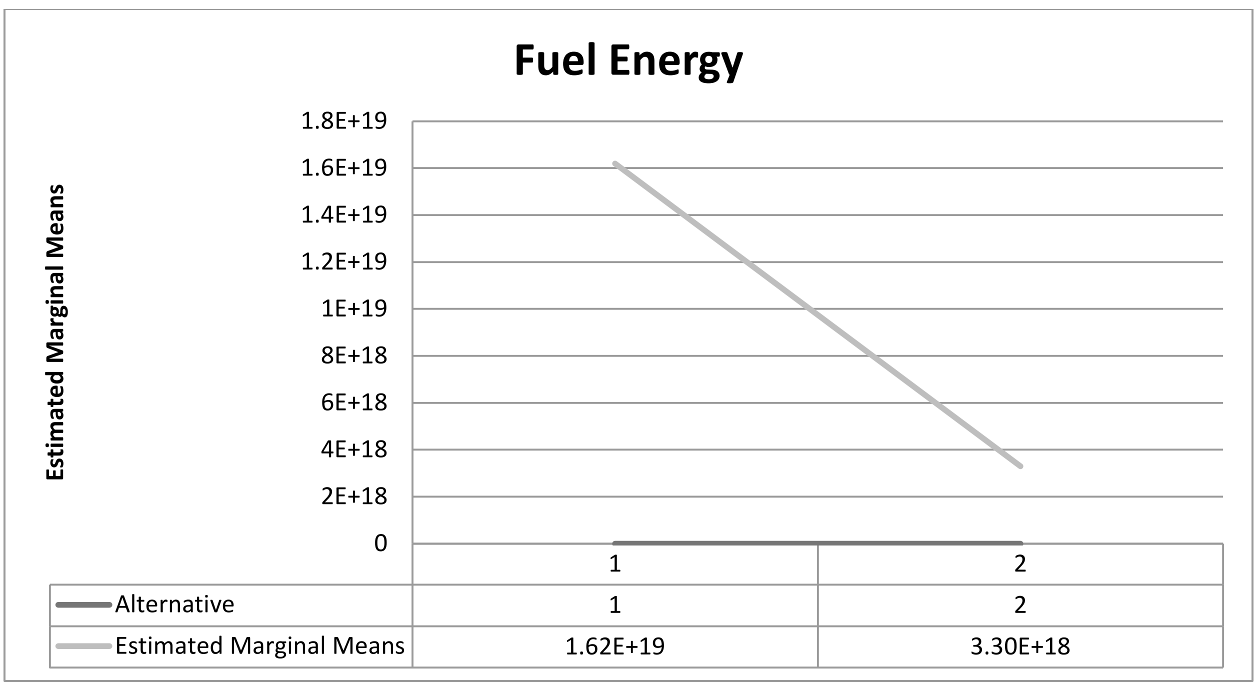


Figure 19. Profile Plot - Fuel Energy

Figure 20. Profile Plot - Goods

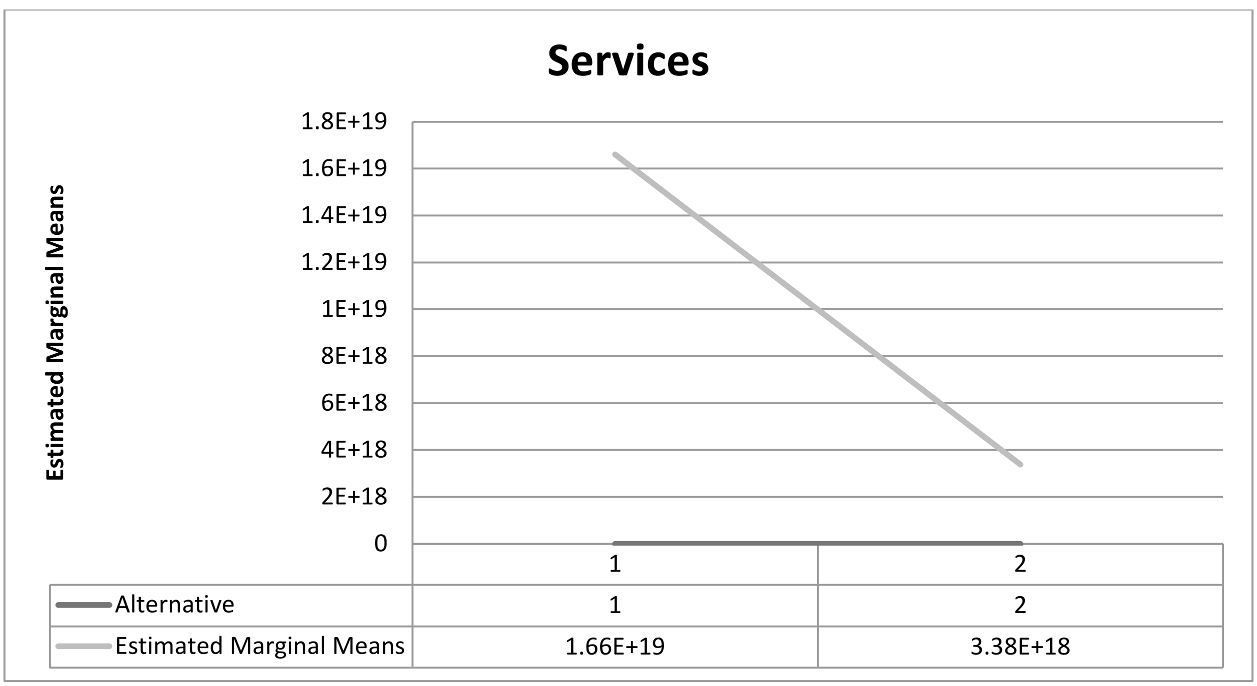


Figure 21. Profile Plot - Services

Statistical Significance

Given the fact that the significance was greater than the alpha value, the null hypothesis was not rejected. Based upon this information, there was no significant difference in terms of environmental impacts to natural resources between the construction of high-speed passenger rail and interstate passenger car transportation. As a result of not rejecting the null hypothesis, an independent sample *t* test was not conducted.

CHAPTER 5

RESULTS

Chapter 5 discusses the results (findings) obtained from the EVE EMERGY analysis rubric that compared high-speed passenger rail and interstate passenger car transportation alternatives through a fixed distance. The results outlined in this chapter are specific to this analysis at this location such that the conclusions cannot be extrapolated without a specific evaluation of the parameters of the project to include but not be limited to the following variables:

1. Project location
2. Typical detail
3. Traffic count
4. Project length
5. Population density
6. Passenger capacity and frequency of train set

Additionally, this dissertation outlines future areas of research that could be conducted to advance the findings reached in this study. A review of the delimitations and limitations associated with this dissertation are as follows:

Delimitations

1. Although the methodology used in this dissertation is applicable to other sites, the conclusion is site specific. As such, future sites should be analyzed independently of the data obtained for this project. Items that could impact the analysis include the following:
    a. Population density
    b. Number of rail cars in the train set
    c. Frequency of train service
    d. Typical design detail for rail line and interstate highway
2. The following items have been excluded from the one mile project length:
    a. Entry and exit ramps
    b. Gas stations
    c. Passenger terminals
    d. Maintenance yards

Limitations

1. Limiting it to two modes of passenger transportation consisting of high-speed passenger rail and interstate passenger car transportation.
2. The evaluation for each alternative was limited to one mile in length.
3. Evaluate the criteria for the construction of double railroad tracks. The use of double tracks facilitated unimpeded movement in both directions and simulated the existing use of the interstate system by passenger cars.
4. Evaluate the construction of two travel lanes in each direction of the interstate. This approach was consistent with the current use of the interstate system by passenger cars.

5. For the purpose of this study, it was projected that each automobile would carry 1.59 passengers per vehicle, (U. S. Department of Energy, 2010).
6. Although the Amtrak Acela train set was proposed for utilization in this study, it was noted that Amtrak planned to replace the Acela line rather than upgrade it (Smith, 2012). To date, Amtrak has not identified a manufacturer for the replacement train set. Amtrak Acela (2012) indicated that each Acela train set consists of :
   d. Power car: 2 (one front and one rear)
   e. Passenger Rail Cars
      j. First class: 1 (seats 44)
      ii. Business class quiet: 1 (seats 65)
      iii. Business class: 3 (seats 65)
      iv. Café/Bistro car: 1
   f. This version of Amtrak's train set carried 304 passengers per trip. A review of the North Carolina's Amtrak by train website (n.d.), indicated that four trains operate between Raleigh, North Carolina and Charlotte, North Carolina in an approximate 12-hour period. Using the Acela train set, this equated to a passenger carrying capacity of 1,216 passengers in an approximate 12-hour period.
7. The North Carolina Department of Transportation (2004) indicated a total count of 15,867 northbound passenger cars and a total count of 19,059 southbound passenger cars in a 12-hour period passed through survey site five (Centergrove) along Interstate 85. For pavement design purposes, the traffic count at survey site five (Centergrove) was projected at a 2014 average daily traffic (ADT) of 39,114 and at a 2034 ADT of 48,633 with 6% duals and 12% truck, tractor and semi-trailer (TTST) (C. Morrison, personal

communication, February 21, 2014). For this evaluation, automobiles accounted for approximately 80% of ADT which yielded 31,291 vehicles per day. The U. S. vehicle occupancy rate was an average of 1.59 passengers per car (U. S. Department of Energy, 2010). The interstate option would yield an average transport level of 49,753 passengers in a 24-hour time period or 24,876.5 passengers in a 12-hour period.

8. High-speed passenger rail and interstate passenger car alternatives were compared based on EMERGY per passenger mile.
9. The evaluation of greenhouse gas emission could be based on a composite analysis and incorporation of existing data as obtained from the EPA, the U. S. Department of Transportation, applicable designers, and manufacturers for automobiles and high-speed passenger trains. This was acknowledged as future areas of research for incorporation into a modified EVE analysis. The term developed in this proposal to define that analysis is a Comprehensive Environmental Return on Investment (CE-ROI).
10. It was noted that interstate highway design utilized truck traffic rather than automobile traffic as a determinant for base and pavement thickness. As such, the design utilized in this study exceeded that required to exclusively transport automobiles (C. Morrison, personal communication, February 21, 2014).

Comparison of Total Phase EMERGY Input by Alternative

Table 30 presents a Comparison of the Total Phased EMERGY by Alternative.

Table 30

Comparison of Total Phased EMERGY by Alternative

EVE Phase	Transportation Alternative
A-C: Transformity	Alternative 2 (interstate passenger car) used 3.9 times more EMERGY
D: Design	Not Applicable
E: Component Production	Alternative 1 (high-speed passenger rail) used 1.22 E 21 times more EMERGY
F: Construction	Alternative 1 (high-speed passenger rail) used 2.1 times more EMERGY
G: Use	Alternative 2 (interstate passenger car) used 3.7 times more EMERGY
H: Demolition	Not Applicable
I: Natural Resource Recycling	Not Applicable
J: Disposal	Not Applicable
Total EMERGY	Alternative 1 (high-speed passenger rail) used 5 times more total EMERGY

A general observation of data presented in Table 14 Total Phase EMERGY Input for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) is as follows:

1. An analysis of the transformity phase indicated that Alternative 1 (high-speed passenger rail) used less EMERGY for this phase than Alternative 2 (interstate passenger car) transportation alternative.

2. The design phase for both alternatives was considered to be above average in terms of complexity and, therefore, approximately equivalent in terms of the level of effort required to complete each of them.
3. The component production was higher for the high-speed passenger rail option due to the production of steel rail, rebar, fasteners, and concrete cross ties. There was no component production involved with the interstate passenger car alternative.
4. In the construction phase, Alternative 1 (high-speed passenger rail) used more EMERGY than Alternative 2 (interstate passenger car) transportation alternative. Two different methods of rail construction were evaluated in an effort to determine if one offered a relative advantage over the other. The initial method used during construction involved the use of traditional equipment such as back hoes and excavators. The resulting EMERGY associated with cross ties and rail was 9.96 E 17 sej. The method of construction utilized during the subsequent track replacement was based upon the utilization of a track replacement machine. It should be noted that this machine removes and installs cross ties and rail simultaneously. The resulting EMERGY associated with this event was 2.45 E 18 sej. Although the EMERGY increased with the utilization of the track replacement machine, additional benefits included demolition of existing cross ties and rail as well as a sustainable effort for installing cross ties and rail over long distances. Although there was a difference in EMERGY between the installation methods, the net difference between the methods did not impact the final outcome between the high-speed passenger rail and interstate passenger car alternatives.

5. During the Use Phase, Alternative 2 (interstate passenger car) had a higher EMERGY use than Alternative 1 (high-speed passenger rail). This can be explained by the applicable frequency of maintenance required by the interstate consisting of resurfacing, milling, and asphalt replacement.
6. The Demolition Phase was not applicable given the fact that with the high-speed passenger rail alternative, the demolition effort was included in the track replacement as a result of using the track replacement machine. Ultimately, this machine combined concrete cross tie and rail removal along with concrete cross tie and rail installation. The demolition associated with the interstate was included in preparation for new pavement installation. Subsequently, the preparation included milling, removal, hauling, preparation, and new pavement installation.
7. Natural resource recycling was not analyzed separately in this analysis.
8. Disposal was not analyzed separately in this analysis as each transportation alternative was reevaluated for actions required to continued use for another lifecycle with no anticipated end-of-life period to be realized.

High-Speed Passenger Rail EMERGY Review

For the purpose of this analysis, the high-speed passenger rail alternative required the design and construction of dual, electrified tracks and did not take into consideration the fact that tracks could be shared for the purpose of transporting dual cargos such as freight and passengers. A review of the EVE phases associated with this alternative indicated that the component production was the area that had the greatest impact on total EMERGY use. The primary components associated with this were concrete cross ties, electrification, steel rail, and steel fasteners. Based upon this finding, the focus on reducing the environmental impacts of the components associated with this phase would result in the greatest reduction of EMERGY associated with natural resource impacts. Table 31 contains a summary of the percentage of EMERGY allocated per phase for Alternative 1 (high-speed passenger rail). Refer to Figure 22 for the graph of Alternative 1 (high-speed passenger rail) total EMERGY.

Table 31

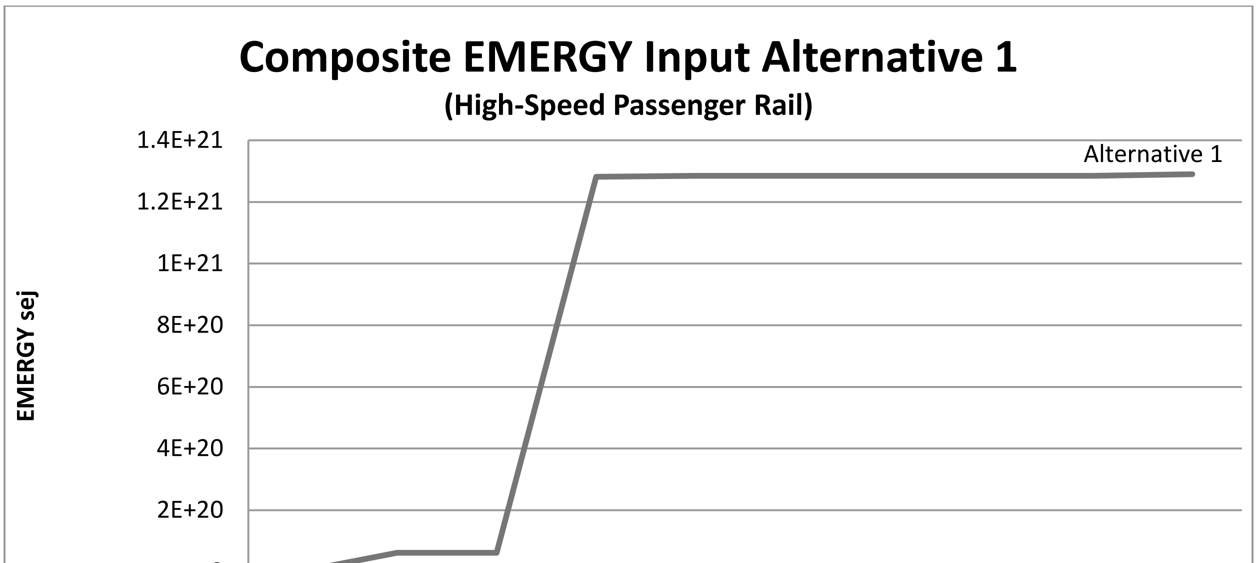
EVE EMERGY Summary Alternative 1 (High-Speed Passenger Rail)

EVE Phase	Alternative 1
A-C: Transformity	4.84%
D: Design	0.00%
E: Component Production	94.57%
F: Construction	0.48%
G: Use	0.03%
H: Demolition	0.00%
I: Natural Resource Recycling	0.00%
J: Disposal	0.00%
Total EMERGY	99.89%

A review of the data presented in Table 31 for Alternative 1 (high-speed passenger rail) is as follows:

1. The Transformity Phase accounted for 4.84% of the total EMERGY.
2. The Design Phase did not contribute to total EMERGY.

3. The Component Production Phase accounted for 94.57% of the total EMERGY. This value indicated that the largest EMERGY contribution among all phase occurred here.
4. The Construction Phase accounted for 0.48% of total EMERGY.
5. The Use Phase accounted for 0.03% of total EMERGY.
6. The Demolition Phase did not contribute to total EMERGY.
7. The natural resource Recycling Phase did not contribute to total EMERGY.
8. The Disposal Phase did not contribute to total EMERGY.



		A-C	D	E	F	G	H	I	J	Total
Alternative 1	0	6.2E+19	6.2E+19	1.3E+21	1.3E+21	1.3E+21	1.3E+21	1.3E+21	1.3E+21	1.3E+21

Figure 22. Composite EMERGY Alternative 1 (High-Speed Passenger Rail)

A review of the data presented in Figure 22 for Alternative 1 (high-speed passenger rail) is as follows:

1. The greatest EMERGY contribution occurred in the Component Production Phase.

2. Additional EMERGY contributions by phase were negligible relative to the component production phase.

A review of the above presentation of data indicates that high-speed passenger rail has a majority of its EMERGY contribution occurring in the Component Production Phase. When this value is compared to EMERGY for the Transformity, Construction, and Use Phases, its order of magnitude confirmed that future work should be focused in this area in an effort to reduce the impact that high-speed passenger rail has on the environment. The area of concentration could specifically focus on concrete cross ties, rail, fasteners, and rebar.

Interstate Highway Transportation EMERGY Review

This analysis evaluated a project that was designed based upon a requirement to carry truck traffic in addition to passenger cars. Although a typical road section designed only for car traffic would result in smaller EMERGY values, such a limitation of design and construction would not be acceptable given the resulting limited use that would result from it. Additionally, the interstate highway, as designed and constructed in this analysis, would provide the benefit of transporting other classifications of traffic such as bus and cargo of various types via semi-trucks. Refer to Table 32 for a review of the EMERGY values associated with transportation Alternative 2 (interstate passenger car) indicated that the Transformity Phase (A-C) utilized the greatest amount of EMERGY. This phase included natural resource formation, natural resource exploration, and extraction and material production. The only option available to reduce the EMERGY outcome would be the development of efficient measures for natural resource exploration and extraction.

Table 32

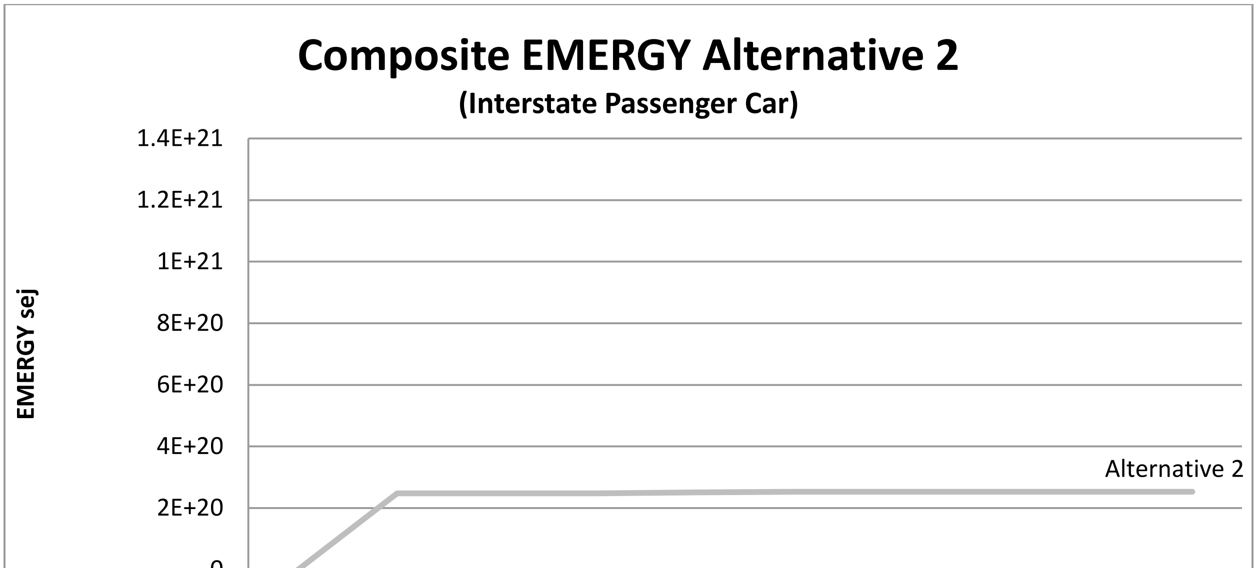
EVE EMERGY Summary Alternative 2 (Interstate Passenger Car)

EVE Phase	Alternative 2
A-C: Transformity	97.22%
D: Design	0.00%
E: Component Production	0.00%
F: Construction	1.17%
G: Use	0.65%
H: Demolition	0.00%
I: Natural Resource Recycling	0.00%
J: Disposal	0.00%
Total EMERGY	99.04%

A review of the data presented in Table 32 for Alternative 2 (interstate passenger car) is as follows:

1. The Transformity Phase accounted for 97.22% of the total EMERGY. This value indicated that the largest EMERGY contribution among all phases occurred here.
2. The Design Phase did not contribute to total EMERGY.
3. The Component Production Phase did not contribute to total EMERGY.
4. The Construction Phase accounted for 1.17% of the total EMERGY.
5. The Use Phase accounted for 0.65% of the total EMERGY.
6. The Demolition Phase did not contribute to total EMERGY.
7. The natural resource Recycling Phase did not contribute to total EMERGY.
8. The Disposal Phase did not contribute to total EMERGY.

Figure 23 shows the composite EMERGY for Alternative 2 (interstate passenger car).



		A-C	D	E	F	G	H	I	J	Total
Alternative 2	0	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20	2.5E+20

Figure 23. Composite EMERGY Alternative 2 (Interstate Passenger Car)

A review of the data presented in Figure 23 for Alternative 2 (interstate passenger car) is as follows:

1. The greatest EMERGY contribution occurred in the material Transformity Phase.
2. The additional EMERGY contributions by phase were negligible relative to the material transformity phase.
3. A majority of the EMERGY contribution occurred during the material Transformity Phase. A comparison of this EMERGY contribution to that contributed by the Construction and Use Phases confirmed that the other contributions were minor compared to this one. The material Transformity Phase did not offer an opportunity to reduce total EMERGY contribution based upon utilization of existing materials such as gravel, asphalt, and fill dirt.

EMERGY per Passenger Mile Summary of Findings

The EMERGY per passenger mile calculations resulted in the following values.

Alternative 1 High-speed rail EMERGY per passenger mile:

$$= (1.29x10^{21} sej)/(1{,}216\ passengers)(1\ mile)$$

$$= 1.06x10^{18} sej/passenger\ mile$$

Alternative 2 Interstate passenger car transportation EMERGY per passenger mile:

$$= (2.52x10^{20} sej)/(24{,}876.5\ passengers)(1\ mile)$$

$$= 1.01x10^{16} sej/passenger\ mile$$

Refer to Figure 24, EMERGY per Passenger Mile to view the results of the above calculations in chart form for both alternatives. The chart shows EMERGY sej on the vertical axis while the alternatives are listed on the horizontal axis.

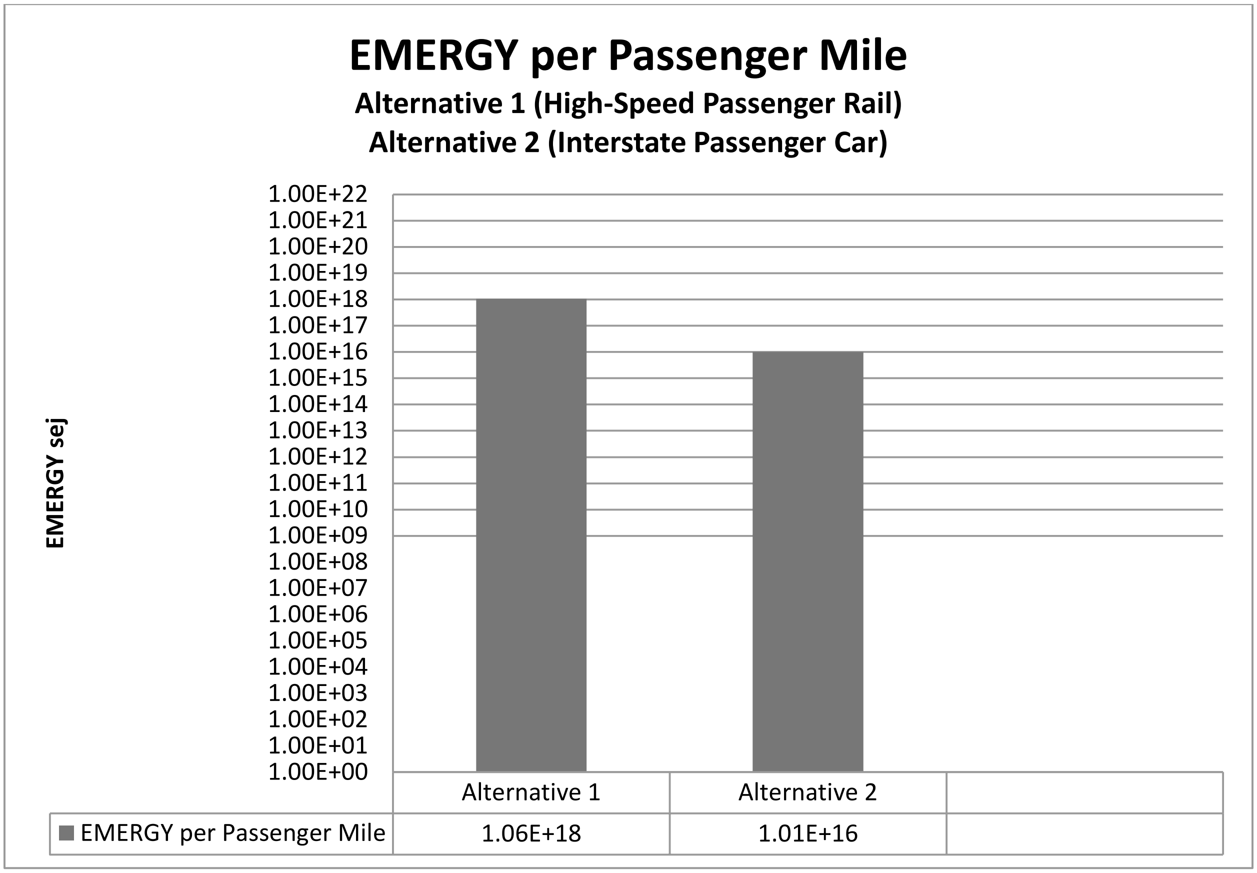


Figure 24. EMERGY per Passenger Mile

A review of Figure 24 indicates that the total EMERGY per passenger mile for the high-speed passenger rail Alternative 1 was greater than the total EMERGY per passenger mile for the interstate passenger car Alternative 2. A closer look at the variables used in the calculation indicated the following:

1. The calculated total EMERGY per passenger mile value for Alternative 1 (high-speed passenger rail) exceeds the calculated total EMERGY per passenger mile value for Alternative 2 (interstate passenger car) by a factor of 104.95.
2. The passenger capacity per mile for Alternative 2 (interstate passenger car) exceeds the passenger capacity per mile for Alternative 1 (high-speed passenger rail) by a factor of 20.5.

3. Each alternative was evaluated over a distance of one mile.

Total EMERGY Summary of Findings

Refer to Figure 25 for a plot of the total EMERGY by alternative. The EMERGY values in solar emjoules are plotted on the vertical axis and the transportation alternatives are plotted on the horizontal axis.

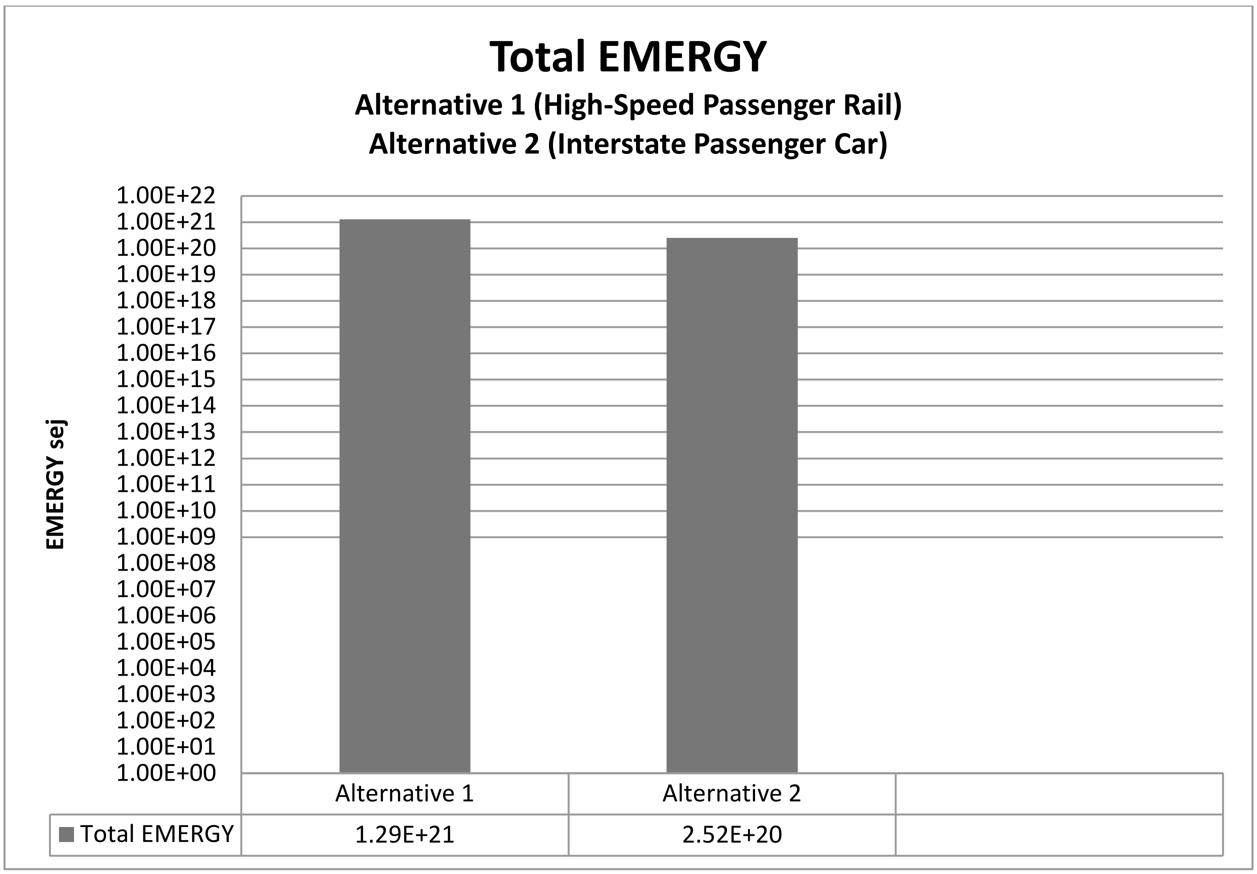


Figure 25. Total EMERGY

A review of Figure 25 indicates that the total EMERGY for Alternative 1 (high-speed passenger rail) exceeds the total EMERGY for Alternative 2 (interstate passenger car) by a factor of 5.1.

Discussion of Problem Statement

The problem of this research was to determine an effective methodology to evaluate the environmental impact of high-speed passenger rail and interstate passenger car transportation through a fixed distance to determine the alternative with the least impact on the environment. Eight methods were reviewed to determine an approach suitable for an environmental analysis for this dissertation. Based upon a review of the following approaches, it was determined that EVE offered the method that was most suitable to evaluate the environmental impact of high-speed passenger rail and interstate passenger car transportation.

1. Carbon Footprint

As noted in Chapter 2, there are substantiated concerns related to greenhouse gas emissions and the resulting need to measure carbon footprint. Carbon footprint in and of itself is not a comprehensive analysis of built environment alternatives and as such was not selected for this dissertation.

2. Ecological Footprint

Ecological footprint involves an analysis of how large an area of productive land should be in order to sustain a defined population. Ecological footprint is well known and has received international attention; however, it does not facilitate the evaluation and comparison of built environment alternatives and as such, was not selected for use in this dissertation.

3. Ecological Economics

Ecological economics has an origin that is related to policy and focuses on the interaction of human economies and their associated ecosystems. Based upon this concept, it is realized that man’s economic growth has a subsequent impact on the environment. Although ecological economics focuses on the relationship between limited resources and economic output, it does not provide an analysis of specific projects within the built environment and was not selected for use in this dissertation.

4. Life Cycle Cost Analysis

Life cycle cost analysis involves total project costs from implementation to decommissioning. The costs are analyzed in terms of net present value with the preferred alternative being the one with the lowest cost. Since life cycle cost does not have an environmental component, it was not selected for use in this dissertation.

5. Embodied Energy

Embodied energy has been defined as the total energy associated within a system and consists of a summation of direct and indirect energy. Since embodied energy does not include work of the environment, it was not selected for use in this dissertation.

6. EMERGY Analysis

EMERGY does not use money as a basis for reaching a decision. Transformities are used to convert energy of different types into energy of one type called EMERGY. Since EMERGY can be used to analyze different energy forms for external inputs that include the environment, it was determined that it would be beneficial to use it in this dissertation.

7. Value Engineering

Value engineering has proven effective at minimizing cost while increasing value improvement through production. Value engineering independent of modifications does not have a component that facilitates an analysis of the environmental impact of built alternatives. Components of value engineering would be beneficial to use in this dissertation.

8. Environmental Value Engineering (EVE)

The comprehensive analysis of EVE combines the application of EMERGY analysis and value engineering in which it looks at the environmental life cycle assessment over 10 phases. The four external inputs consist of environment (E), fuel energy (F), goods (G) and services (S). Based upon this comprehensive approach, EVE was selected for use in this dissertation.

Discussion of Research Questions

What is an effective methodology for evaluating the environmental impact of high-speed passenger rail and interstate passenger car transportation alternatives?

A review of eight evaluation methods indicated that the comprehensive analysis of EVE combined the application of EMERGY analysis and value engineering in which it looked at the environmental life cycle assessment over 10 phases with external inputs of environment (E), fuel energy (F), goods (G) and services (S). This validates selection of EVE in this study.

Which transportation alternative has the least impact on the environment while meeting the need of transporting people?

This research question was effectively evaluated based upon a review of Figures 24 and 25. Figure 24 shows a graph of the EMERGY per passenger mile for each transportation alternative and indicates that Alternative 2 (interstate passenger car) uses less EMERGY per passenger mile than Alternative 1 (high-speed passenger rail) by a factor of 104.95. Figure 25 shows a graph of the total EMERGY used for Alternative 1 (high-speed passenger rail) and Alternative 2 (interstate passenger car) and indicates that Alternative 2 uses less total EMERGY than Alternative 1 by a factor of 5.1.

Statistical Analysis Summary of Findings

A MANOVA was conducted to determine if a significant difference existed between the Aggregated EMERGY Values for the transportation alternatives. A review of the SPSS model did not indicate that a significant difference existed between the high-speed passenger rail Alternative 1 and the interstate passenger car Alternative 2. The SPSS model did point out some constraints with analyzing the data:

1. The data were not normally distributed. There was concern given the fact that it was skewed to the left with a tail to the right as well as concern with the kurtosis value of approximately 14.4 which indicated that the data was distributed in a tall and narrow output.
2. General liner model warnings:
   a. Box's test of equality of covariance matrices were not computed because there were fewer than two nonsingular cell covariance matrices.
   b. Post hoc tests were not performed for the alternative because there were fewer than three alternatives.

Conclusion

Based upon the delimitations and limitations outlined for this specific location, the findings of this study are specific to the conditions outlined in this project and indicate that Alternative 1 (high-speed passenger rail) has a greater impact on the environment than Alternative 2 (interstate passenger car transportation) with project specific findings as follows:

1. An evaluation of EMERGY per passenger mile indicated that Alternative 1 (high-speed passenger rail) used more EMERGY per passenger mile than Alternative 2 (interstate passenger car) by a factor of 104.95.

2. An evaluation of total EMERGY indicated that Alternative 1 (high-speed passenger rail) used more total EMERGY than Alternative 2(interstate passenger car) by a factor of 5.1.

Future Research and Applications

Although this EVE EMERGY analysis provided the results of a rubric that compared high-speed passenger rail and interstate passenger car transportation alternative, there are applicable areas of future research that should be considered.

1. Comprehensive environmental return on investment (CE-ROI). This is a term that was defined and copyrighted during this study and includes additional components and impact variables that can be included in the EVE analysis.
    a. Expand the EVE Emergy analysis to include the material composition of the high-speed passenger rail train and passenger cars. The potential benefit to be gained from this inclusion will consist of minimizing impact to environmental resources during the construction of these components and minimizing the impact to landfill space at the time of disposal of these components.
    b. Greenhouse gas emissions. Include an EVE EMERGY analysis of greenhouse gas emissions for both transportation alternatives. This expanded evaluation will provide insight into the critical issue of global warming by further evaluating the additional impact that transportation alternatives may have on the environment.
    c. Fuel analysis. Include fuel usage into the EVE EMERGY analysis. A review of fuel usage could accurately be evaluated along with greenhouse gas emissions given the correlation between the consumption of fuel for energy to move passengers and the emission of greenhouse gases as a result of fuel consumption.

d. Given the limited number of resources and the growing population that is competing for them, it is conceivable that major built environment alternatives will be evaluated from multiple perspectives within a CE-ROI to include EVE, Carbon Footprint, Ecological Footprint and Ecological Economics.

2. Environmental complexity factor. This term was defined and copyrighted during this study and stated that the more complex an environmental issue is, the longer it will take before society responds. The premise is that the delay is due to conflict resolution more so than due to the lack of a technical solution. Further study to evaluate this assumption can be beneficial to providing policy makers with guidelines on evaluating environmental challenges and formulating a subsequent response without delay.
3. Consideration of future material research could prove beneficial in identifying alternative materials that would minimize the total EMERGY contribution and subsequently reduce the impact to the environment for both alternatives. A modified CE-ROI can provide a means for evaluating future built environment alternatives that will be guided by the development of advanced materials and technology.
4. Additional research can be focused on establishing new transformity values as it relates to the four inputs and additional research can be done to further refine the percentage of allocation among the four inputs of environment (E), fuel energy (F), goods (G) and services (S).
5. Advance the composite method of an environmental analysis in conjunction with the development of future materials, compulsion sources and built environment alternatives.

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APPENDIX A: ENVIRONMENTAL IMPACT EMERGY INPUT SOURCES

Source. Roudebush (1992).

PHASE A. Natural Resource Formation

- E. Environment (renewable)
  - El. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1)Sun
    - (2)Earth
  - E4. Land
    - (1)Area
    - (2)Resources
  - E5. Water
    - (1)Area
    - (2)Resources
  - F. Fuel Energy (nonrenewable):none
  - G. Goods:none
  - S. Services (labor):none

PHASE B. Natural Resource Exploration and Extraction

- E. Environment (renewable)
  - El. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1)Sun (2)
    - Earth
  - E4. Land
    - (1)Area
    - (2)Resources
  - E5. Water
    - (1)Area
    - (2)Resources
  - E6. Materials
- F. Fuel Energy (nonrenewable)
  - Fl. Equipment
  - F2. Facilities
  - F3. Materials
- G. Goods
  - Gl. Equipment
  - G2. Facilities
  - G3. Materials
  - G4. Tools
- S. Services

Sl. Labor
S2. Materials

PHASE C Material Production
E. Environment (renewable)
El. Atmosphere
E2. Ecological production
E3. Energy
(1) Sun
(2) Earth
E4. Land
(1) Area
(2) Resources
E5. Water
(1) Area
(2) Resources
E6. Materials
F. Fuel Energy (nonrenewable)
Fl. Equipment
F2. Facilities
F3. Materials
G. Goods
Gl. Equipment
G2. Facilities
G3. Materials
G4. Tools
S. Services
Sl. Labor
S2. Materials

PHASE D. Design (Architectural and Engineering) E.
E. Environment (renewable)
El. Atmosphere
E2. Ecological production
E3. Energy
(1) Sun
(2) Earth
E4. Land
(1} Area
(2) Resources
E5. Water
(1) Area
(2) Resources
E6. Materials
F. Fuel Energy (nonrenewable)
Fl. Equipment
F2. Facilities
F3. Materials
G. Goods
Gl. Equipment
G2. Facilities
G3. Materials

- G4. Tools

S. Services
- Sl. Labor
- S2. Materials

PHASE E. Component Production
- E. Environment (renewable)
  - El. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1) Sun
    - (2) Earth
  - E4. Land
    - (1) Area
    - (2) Resources
  - E5. Water
    - (1) Area
    - (2) Resources
  - E6. Materials
- F. Fuel Energy (nonrenewable)
  - Fl. Equipment
  - F2. Facilities
  - F3. Materials
- G. Goods
  - Gl. Equipment
  - G2. Facilities
  - G3. Materials
  - G4. Tools
- S. Services
  - Sl. Labor
  - S2. Materials

PHASE F. Construction
- E. Environment (renewable)
  - El. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1) Sun
    - (2) Earth
  - E4. Land
    - (1) Area
    - (2) Resources
  - E5. Water
    - (1) Area
    - (2) Resources
  - E6. Materials
- F. Fuel Energy (nonrenewable)
  - Fl. Equipment
  - F2. Facilities
  - F3. Materials
- G. Goods

G1. Equipment
G2. Facilities
G3. Materials
G4. Tools
S. Services
S1. Labor
S2. Materials

PHASE G. Use
E. Environment (renewable)
E1. Atmosphere
E2. Ecological production
E3. Energy (1)
Sun (2)
Earth
E4. Land
(1) Area
(2) Resources
E5. Water
(1) Area
(2) Resources
E6. Materials
F. Fuel Energy (nonrenewable)
F1. Equipment
F2. Facilities
F3. Materials
G. Goods
G1. Equipment
G2. Facilities
G3. Materials
G4. Tools
S. Services
S1. Labor
S2. Materials

PHASE H. Demolition
E. Environment (renewable)
E1. Atmosphere
E2. Ecological production
E3. Energy
(1) Sun
(2) Earth
E4. Land
(1) Area
(2) Resources
E5. Water
(1) Area
(2) Resources
E6. Materials
F. Fuel Energy (nonrenewable)
F1. Equipment
F2. Facilities

F3. Materials
G. Goods
Gl. Equipment
G2. Facilities
G3. Materials
G4. Tools
S. Services
Sl. Labor
S2. Materials

PHASE I. Natural Resource Recycling
E. Environment (renewable)
El. Atmosphere
E2. Ecological production
E3. Energy
(1)Sun
(2)Earth
E4. Land
(1)Area
(2) Resources
E5. Water
(1)Area
(2)Resources
E6. Materials
F. Fuel Energy (nonrenewable)
Fl.
Equipment
F2. Facilities
F3. Materials
G. Goods
Gl. Equipment
G2. Facilities
G3. Materials
G4. Tools
S. Services
Sl. Labor
S2. Materials

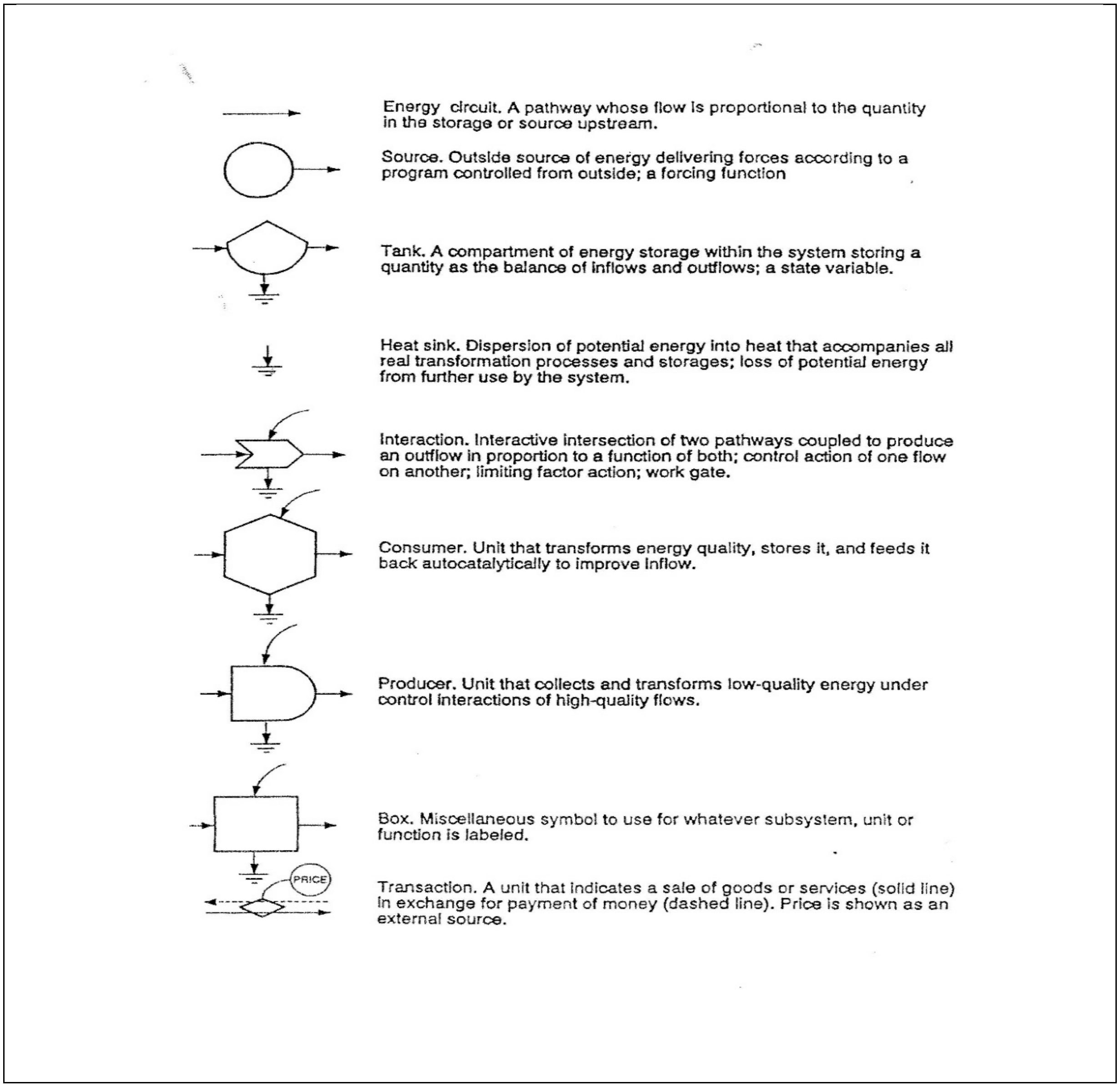
PHASE J. Disposal
E. Environment (renewable)
El. Atmosphere
E2. Ecological production
E3. Energy
(1)Sun
(2)Earth
E4. Land
(1)Area
(2)Resources
E5. Water
(1)Area
(2)Resources
E6. Materials
F. FuelEnergy (nonrenewable)

- Fl. Equipment
- F2. Facilities
- F3. Materials

G. Goods
- Gl. Equipment
- G2. Facilities
- G3. Materials
- G4. Tools

S. Services
- Sl. Labor
- S2. Materials

APPENDIX B: ENERGY SYSTEMS DIAGRAM SYMBOLS AND LANGUAGE



(Roudebush, 1996)

APPENDIX C: EMERGY INPUT TABLES

Group 1 High-Speed Passenger Rail Transportation Alternative 1
Table HSPR-1: Material Transformity Phases A-C
Top Soil

		Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table		
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$16.77\ x10^{9}\ g$	$1.71\ x10^{9}$	$2.87\ x10^{19}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$2.4\ x10^{9}\ g$	$1.71\ x10^{9}$	$4.10\ x10^{18}\ sej$
G	GOODS	$2.4\ x10^{9}\ g$	$1.71\ x10^{9}$	$4.10\ x10^{18}\ sej$
S	SERVICES	$2.4\ x10^{9}\ g$	$1.71\ x10^{9}$	$4.10\ x10^{18}\ sej$

Table HSPR-1: Material Transformity Phases A-C
Top Soil

Material: Soil with balanced cut and fill

Soil transformity = $1.71\ x10^{9}$ sej/g

Unit weight of soil ~ 100 $\frac{lbs}{CF}$

Mass (Grading) = $(1\ ft)(100\ ft)(5{,}280\ ft)^{1}(100\ \frac{LB}{CF})(\frac{453.6\ g}{lb})$

Mass (Grading) = $23.95\ x10^{9}\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(23.95x10^{9}g)$$

$$= 16.77x10^{9}\ g$$

$$Solar\ EMERGY = (16.77x10^{9}g)(1.71x10^{9}\,\frac{sej}{g})$$

$$= 2.87\ x10^{19}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(23.95x10^{9}g)$$

$$= 2.40x10^{9}\ g$$

$$Solar\ EMERGY = (2.40x10^{9}g)(1.71x10^{9}\,\frac{sej}{g})$$

$$= 4.10\ x10^{18}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(23.95x10^{9}g)$$

$$= 2.40x10^{9}\ g$$

$$Solar\ EMERGY = (2.40x10^{9}g)(1.71x10^{9}\,\frac{sej}{g})$$

$$= 4.10\ x10^{18}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(23.95x10^{9}g)$$

$$= 2.40x10^{9}\ g$$

$$Solar\ EMERGY = (2.40x10^{9}g)(1.71x10^{9}\frac{sej}{g})$$

$$= 4.10\ x10^{18}\ sej$$

Table HSPR-2 Material Transformity Phases A-C
Subballast 6 Inch Aggregate Base Course

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$2.96\ x10^9\ g$	$1.00\ x10^9$	$2.96\ x10^{18}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$423\ x10^6\ g$	$8.5\ x10^8$	$3.6\ x10^{17}\ sej$
G	GOODS	$423\ x10^6\ g$	$8.5\ x10^8$	$3.6\ x10^{17}\ sej$
S	SERVICES	$423\ x10^6\ g$	$8.5\ x10^8$	$3.6\ x10^{17}\ sej$

Table HSPR-2: Material Transformity Phases A-C
Subballast 6 Inch Aggregate Base Course

Material: Stone Aggregate

Stone (mined) transformity = $1.00\ x10^9$ sej/g

Specific weight compacted = 3180 lb/cy

Volume $= (30\ ft)(5{,}280\ ft)^1(\frac{6}{12}ft)\left(\frac{1CY}{27\ CF}\right)$

$= 2{,}933.3\ CY$

Mass $= (2{,}933.3\ CY)\left(\frac{3{,}180\ lb}{CY}\right)(\frac{453.6\ g}{lb})$

$= 4.23\ x10^9\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(4.23x10^9 g)$$

$$= 2.96\ x10^9 g$$

$$Solar\ EMERGY = (2.96x10^9 g)(1.00x10^9 \frac{sej}{g})$$

$$= 2.96\ x10^{18}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(4.23x10^9 g)$$

$$=423x10^6 g$$

$$Solar\ EMERGY = (423x10^6 g)(8.5x10^8 \frac{sej}{g})$$

$$= 3.6x10^{17}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(4.23x10^{9}g)$$

$$=423x10^{6}g$$

$$Solar\ EMERGY = (423x10^{6}g)(8.5x10^{8}\frac{sej}{g})$$

$$= 3.6x10^{17}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(4.23x10^{9}g)$$

$$=423x10^{6}g$$

$$Solar\ EMERGY = (423x10^{6}g)(8.5x10^{8}\frac{sej}{g})$$

$$= 3.6x10^{17}\ sej$$

Table HSPR-3: Material Transformity Phases A-C
Rail Ballast
– Original Construction
– Use Phase

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$12.66\ x10^{9}\ g$	$1.00\ x10^{9}$	$1.27\ x10^{19}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$8.5\ x10^{8}\ g$	$1.00\ x10^{9}$	$1.54\ x10^{18}\ sej$
G	GOODS	$8.5\ x10^{8}\ g$	$1.00\ x10^{9}$	$1.54\ x10^{18}\ sej$
S	SERVICES	$8.5\ x10^{8}\ g$	$1.00\ x10^{9}$	$1.54\ x10^{18}\ sej$

Table HSPR-3: Material Transformity Phases A-C
Rail Ballast
– Original Construction
– Use Phase

Material: Railroad Aggregate

Stone (mined) transformity = $1.00\ x10^9$ sej/g

Stone specific weight (compacted) = 2,719 lb/CY

Volume $= 30\ ft\left(12\ in\ *\ \frac{1ft}{12\ in}\right)(5{,}280\ ft)^1\left(\frac{1CY}{27\ CF}\right)$

$= 5{,}866.7\ CY$

Volume $= 30\ ft\left(6\ in\ *\ \frac{1ft}{12\ in}\right)(5{,}280\ ft)^1\left(\frac{1CY}{27\ CF}\right)$

$= 2{,}933.3\ CY$

Volume $= 30ft\left(12\ in\ *\ \frac{1ft}{12\ in}\right)(5{,}280\ ft)^1\left(\frac{1CY}{27\ CF}\right)$

$= 5{,}866.7\ CY$

Volume Total $= 14{,}666.7\ CY$

Mass $= 14{,}666.7CY\left(\frac{2{,}719\ lb}{CY}\right)(\frac{453.6\ g}{lb})$

$= 18.09\ x10^9\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(18.09x10^9 g)$$

$$= 12.66\ x10^9 g$$

$$Solar\ EMERGY = (12.66x10^9 g)(1.00x10^9\,\frac{sej}{g})$$

$$= 1.27\ x10^{19}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(18.09x10^9 g)$$

$$=1.81x10^9 g$$

$$Solar\ EMERGY = (1.81x10^9 g)(8.5x10^8 \frac{sej}{g})$$

$$= 1.54x10^{18}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(18.09x10^9 g)$$

$$=1.81x10^9 g$$

$$Solar\ EMERGY = (1.81x10^9 g)(8.5x10^8 \frac{sej}{g})$$

$$= 1.54x10^{18}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(18.09x10^9 g)$$

$$=1.81x10^9 g$$

$$Solar\ EMERGY = (1.81x10^9 g)(8.5x10^8 \frac{sej}{g})$$

$$= 1.54x10^{18}\ sej$$

Table HSPR-4: Design Phase D
Phase-D: EMERGY Input – Rail Option

Phase-D Design (Architectural and Engineering) Environmental Value Engineering EMERGY Analysis Input Table				
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY associated with design was not calculated separately based upon the assumption that the design for high-speed passenger rail and interstate passenger car transportation were both of above average complexity and as such assumed equivalent for this analysis.

Table HSPR-4: Design Phase D

Design

The EMERGY associated with design was not calculated separately based upon the assumption that the design for high-speed passenger rail and interstate passenger car transportation were both of above average complexity and as such assumed equivalent for this analysis.

Table HSPR-5: Component Production Phase E
Concrete Ties – 5,280 Original Construction
5,280 Use Phase

Phase-E Component Production
Environmental Value Engineering EMERGY Analysis Input Table

Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	*	*	$2.70\ x10^{18} sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	*	*	$3.86\ x10^{17} sej$
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	*	*	$3.86\ x10^{17} sej$
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	*	*	$3.86\ x10^{17} sej$
S-1	Labor	N/A		
S-2	Materials	N/A		

- Raw Units and Transformity values were composites for the steel and concrete components in each tie. Refer to calculations for specifics.

Table HSPR-5: Component Production Phase E
Concrete Ties – 5,280 Original Construction and 5,280 Use Phase

Material: Concrete transformity = $9.99\ x10^{8}$ sej/g
Steel transformity = $1.80\ x10^{9}$ sej/g

Total Mass (Concrete Tie) = 780 $\frac{lbs}{tie}$

Rebar: 3/8 inch rebar weighs 0.376 lb/LF

$$\text{Mass} = \left(8\frac{ft}{strands}\right)(8\ \frac{strands}{tie})(0.376\ \frac{lb}{lf})(10{,}560\ ties)^{1}(\frac{453.6\ g}{lb})$$

$= 115.27\ x10^{6}\ g$ of steel - rebar

Bolts and fasteners: 4 bolts and 4 fasteners per tie (assume 1 lb each) say 8 lbs. total

$$\text{Mass} = (8\ \frac{lbs}{tie})\ (10{,}560\ ties)^{1}(\frac{453.6\ g}{lb})$$

$= 38.32\ x10^{6}\ g$ of steel bolts and fasteners

Total steel = $153.59\ x10^{6}\ g$

Mass (steel) per Concrete Tie = $\left(24\frac{lbs}{tie}\ rebar\right) + (8\frac{lbs}{tie}\ bolts\ and\ fasteners)$

Mass (Concrete) = 780 $\frac{lbs}{tie}$ - 32 $\frac{lbs}{tie}$

= 748 $\frac{lbs}{tie}$

$$\text{Mass (concrete)} = \left(748\frac{lbs}{tie}\right)(10{,}560\ ties)^{1}(\frac{453.6\ g}{lb})$$

Total concrete $= 3.58\ x10^{9}\ g$

EMERGY Calculation for Concrete

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(3.58x10^{9}g)$$

$$= 2.51\ x10^{9}\ g$$

$$Solar\ EMERGY = (2.51x10^{9}g)(9.99x10^{8}\ \frac{sej}{g})$$

$$= 2.51x10^{18}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(3.58x10^{9}g)$$

$$= 358\ x10^{6}\ g$$

$$Solar\ EMERGY = (358x10^{6}g)(9.99x10^{8}\frac{sej}{g})$$

$$= 3.58\ x10^{17}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(3.58x10^{9}g)$$

$$= 358\ x10^{6}\ g$$

$$Solar\ EMERGY = (358x10^{6}g)(9.99x10^{8}\frac{sej}{g})$$

$$= 3.58\ x10^{17}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(3.58x10^{9}g)$$

$$= 358\ x10^{6}\ g$$

$$Solar\ EMERGY = (358x10^{6}g)(9.99x10^{8}\frac{sej}{g})$$

$$= 3.58\ x10^{17}\ sej$$

EMERGY Calculation for Steel

Total Steel =153.59 $x10^{6}\ g$

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(153.59x10^{6}g)$$

$$= 107.51x10^{6}\ g$$

$$Solar\ EMERGY = (107.51x10^{6}g)(1.80x10^{9}\frac{sej}{g})$$

$$= 1.94x10^{17}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(153.59x10^6 g)$$

$$= 15.36x10^6\ g$$

$$Solar\ EMERGY = (15.36x10^6 g)(1.80x10^9 \frac{sej}{g})$$

$$= 2.76x10^{16}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(153.59x10^6 g)$$

$$= 15.36x10^6\ g$$

$$Solar\ EMERGY = (15.36x10^6 g)(1.80x10^9 \frac{sej}{g})$$

$$= 2.76x10^{16}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(153.59x10^6 g)$$

$$= 15.36x10^6\ g$$

$$Solar\ EMERGY = (15.36x10^6 g)(1.80x10^9 \frac{sej}{g})$$

$$= 2.76x10^{16}\ sej$$

EMERGY for composite concrete railroad ties

Environment: $2.51\ x10^{18}\ sej + 1.94\ x10^{17}\ sej = 2.70\ x10^{18} sej$

Fuel Energy: $3.58\ x10^{17}\ sej + 2.76\ x10^{16}\ sej = 3.86\ x10^{17} sej$

Goods: $3.58\ x10^{17}\ sej + 2.76\ x10^{16}\ sej = 3.86x10^{17} sej$

Services: $3.58\ x10^{17}\ sej + 2.76\ x10^{16}\ sej = 3.86\ x10^{17} sej$

Table HSPR-6: Component Production Phase E
Polymer Base Plates 5 pounds per tie with 5,280 ties original construction
5 pounds per tie with 5,280 ties for Use Phase

	Phase-E Component Production Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$16.77x10^6\ g$	$3.80x10^8$	$6.37x10^{15}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$2.40x10^6\ g$	$3.80x10^8$	$9.12x10^{14}\ sej$
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.40x10^6\ g$	$3.80x10^8$	$9.12x10^{14}\ sej$
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	$2.40x10^6\ g$	$3.80x10^8$	$9.12x10^{14}\ sej$
S-1	Labor	N/A		
S-2	Materials	N/A		

Table HSPR-6: Component Production Phase E
Polymer Base Plates 5 pounds per tie with 5,280 ties original construction
5 pounds per tie with 5,280 ties for Use Phase

Material: Polymer

Plastic transformity = $3.8\ x10^8$ sej/g

Mass $= (2)\left(5\,\frac{lbs}{tie}\right)(5{,}280\ ties)^1(\frac{453.6\ g}{lb})$

$= \ 23.95\ x10^6\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(23.95x10^6 g)$$

$$= 16.77\ x10^6\ g$$

$$Solar\ EMERGY = (16.77x10^6 g)(3.8x10^8\,\frac{sej}{g})$$

$$= 6.37\ x10^{15}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(23.95x10^6 g)$$

$$= 2.40\ x10^6\ g$$

$$Solar\ EMERGY = (2.40x10^6 g)(3.8x10^8\,\frac{sej}{g})$$

$$= 9.12\ x10^{14}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(23.95x10^6 g)$$

$$= 2.40\ x10^6\ g$$

$$Solar\ EMERGY = (2.40x10^6 g)(3.8x10^8\,\frac{sej}{g})$$

$$= 9.12\ x10^{14}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(23.95x10^6 g)$$

$$= 2.40\ x10^6\ g$$

$$Solar\ EMERGY = (2.40x10^6 g)(3.8x10^8 \frac{sej}{g})$$

$$= 9.12\ x10^{14}\ sej$$

Table HSPR-7: Component Production Phase E
Steel Rail 21,120 LF Initial Construction
21,120 LF Use Phase

	Phase-E Component Production Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$608.01\ x10^{6}\ g$	$1.80\ x10^{9}$	$1.09\ x10^{18}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$86.86\ x10^{6}\ g$	$1.80\ x10^{9}$	$1.56\ x10^{17}\ sej$
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$86.86\ x10^{6}\ g$	$1.80\ x10^{9}$	$1.56\ x10^{17}\ sej$
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	$86.86\ x10^{6}\ g$	$1.80\ x10^{9}$	$1.56\ x10^{17}\ sej$
S-1	Labor	N/A		
S-2	Materials	N/A		

Table HSPR-7: Component Production Phase E
Steel Rail 21,120 LF Initial Construction
21,120 LF Use Phase

Material: Steel Rail

Steel transformity = 1.8 $x10^9$ sej/g

Steel by components:
Rail: 136 lb/YD
Mass $= (136\ \frac{LB}{YD})\ (1\frac{YD}{3ft})\ (8)(5{,}280\ ft)^1(\frac{453.6\ g}{lb})$

$= 868.59\ x10^6\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(868.59x10^6 g)$$

$$= 608.01\ x10^6\ g$$

$$Solar\ EMERGY = (608.01x10^6 g)(1.8x10^9\frac{sej}{g})$$

$$= 1.09x10^{18}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(868.59x10^6 g)$$

$$= 86.86\ x10^6\ g$$

$$Solar\ EMERGY = (86.86x10^6 g)(1.8x10^9\frac{sej}{g})$$

$$= 1.56x10^{17}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(868.59x10^6 g)$$

$$= 86.86\ x10^6\ g$$

$$Solar\ EMERGY = (86.86x10^6 g)(1.8x10^9 \frac{sej}{g})$$

$$= 1.56x10^{17}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(868.59x10^6 g)$$

$$= 86.86\ x10^6\ g$$

$$Solar\ EMERGY = (86.86x10^6 g)(1.8x10^9 \frac{sej}{g})$$

$$= 1.56x10^{17}\ sej$$

Table HSPR-8: Component Production Phase E
Aluminum Transmission Cable

	Phase-E Component Production Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$14.01x10^{6}\ g$	$1.60x10^{10}$	$2.24x10^{17}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$2.00x10^{6}\ g$	$1.60x10^{10}$	$3.20x10^{16}\ sej$
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.00x10^{6}\ g$	$1.60x10^{10}$	$3.20x10^{16}\ sej$
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	$2.00x10^{6}\ g$	$1.60x10^{10}$	$3.20x10^{16}\ sej$
S-1	Labor	N/A		
S-2	Materials	N/A		

Table HSPR-8: Component Production Phase E
Aluminum Transmission Cable

Material: Aluminum

Aluminum transformity $= 1.60\ x10^{10}$ sej/g

Aluminum by components:

Aluminum cable

Mass $= (8\ cables)(\frac{5{,}280\ ft}{cable})$

$= 42.24\ x10^{3}\ ft\ of\ cable$

$= 42.24\ x10^{3}\ ft\ (\frac{1{,}045\ pounds}{1{,}000\ ft})$

$= (44.14\ x10^{3}\ pounds)(453.6\frac{g}{lbs})$

$= 20.02\ x10^{6}\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(20.02x10^{6}g)$$

$$= 14.01\ x10^{6}\ g$$

$$Solar\ EMERGY = (14.01x10^{6}g)(1.60x10^{10}\frac{sej}{g})$$

$$= 2.24x10^{17}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(20.02x10^{6}g)$$

$$= 2.00\ x10^{6}\ g$$

$$Solar\ EMERGY = (2.00x10^{6}g)(1.60x10^{10}\frac{sej}{g})$$

$$= 3.20x10^{16}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(20.02x10^6 g)$$

$$= 2.00\ x10^6\ g$$

$$Solar\ EMERGY = (2.00x10^6 g)(1.60x10^{10} \frac{sej}{g})$$

$$= 3.20x10^{16}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(20.02x10^6 g)$$

$$= 2.00\ x10^6\ g$$

$$Solar\ EMERGY = (2.00x10^6 g)(1.60x10^{10} \frac{sej}{g})$$

$$= 3.20x10^{16}\ sej$$

Table HSPR-9: Component Production Phase E
Steel Light Poles

	Phase-E Component Production Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	*	*	$3.87\ x10^{16} sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	*	*	$5.51\ x10^{15} sej$
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	*	*	$5.51\ x10^{15} sej$
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools			
S	SERVICES	*	*	$5.51\ x10^{15} sej$
S-1	Labor	N/A		
S-2	Materials	N/A		

- Raw units and transformity values are composites for the steel light poles and concrete bases which have steel rebar for reinforcement.

Table HSPR-9: Component Production Phase E
Steel Light Poles

Material: Steel Light Poles and concrete bases with rebar

Steel by components:
30 foot steel light poles

30 ft. steel light poles= $\frac{(2)(5280 \text{ ft})}{80 \text{ ft}}$

$= 132\ light\ poles(500\frac{pounds}{pole})$

$= (66.0\ x10^3\ pounds)(453.6\frac{g}{Lbs})$

$= 29.94\ x10^6\ g$

Concrete base $= 1{,}800\frac{pounds}{pole}(132\ poles)$

$= 237.6\ x10^3\ pounds$ Concrete $(\frac{1\ CY}{4{,}050\ pounds})$

$= 58.7\ CY$

Use 10 pounds of rebar per concrete base

Steel Rebar $= 10\ \frac{pounds}{base}(132\ bases)$

$= (1{,}320\ Lbs)(453.6\frac{g}{Lbs})$

$= 598.75\ x10^3 g$

Concrete base $= 1{,}800\frac{pounds}{pole}(132\ poles)$

$= 237.6\ x10^3\ pounds$ – 1,320 pounds steel

$= 236.28\ x10^3 pounds\ of\ concrete$

Total steel = $29.94\ x10^6\ g +\ 598.75\ x10^3 g$

$= 30.54\ x10^6\ g$

Steel transformity = $1.8\ x10^9$ sej/g

Environment

Transformity due to environment is 70 %

$Raw\ Units = (0.70)(30.54\ x10^6\ g)$

$$= 21.38\ x10^{6}\ g$$

$$Solar\ EMERGY = (21.38x10^{6}g)(1.8x10^{9}\frac{sej}{g})$$

$$= 3.85x10^{16}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(30.54\ x10^{6}\ g)$$

$$= 3.05\ x10^{6}\ g$$

$$Solar\ EMERGY = (3.05x10^{6}g)(1.8x10^{9}\frac{sej}{g})$$

$$= 5.49x10^{15}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(30.54\ x10^{6}\ g)$$

$$= 3.05\ x10^{6}\ g$$

$$Solar\ EMERGY = (3.05x10^{6}g)(1.8x10^{9}\frac{sej}{g})$$

$$= 5.49x10^{15}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(30.54\ x10^{6}\ g)$$

$$= 3.05\ x10^{6}\ g$$

$$Solar\ EMERGY = (3.05x10^{6}g)(1.8x10^{9}\frac{sej}{g})$$

$$= 5.49x10^{15}\ sej$$

Concrete transformity = $9.99\ x10^{8}$ sej/g

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(236.28x10^3\ g)$$

$$= 165.40\ x10^3\ g$$

$$Solar\ EMERGY = (165.48x10^3 g)(9.99x10^8 \frac{sej}{g})$$

$$= 1.65x10^{14}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(236.28x10^3\ g)$$

$$= 23.63\ x10^3\ g$$

$$Solar\ EMERGY = (23.63\ x10^3\ g)(9.99x10^8 \frac{sej}{g})$$

$$= 2.36x10^{13}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(236.28x10^3\ g)$$

$$= 23.63\ x10^3\ g$$

$$Solar\ EMERGY = (23.63\ x10^3\ g)(9.99x10^8 \frac{sej}{g})$$

$$= 2.36x10^{13}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(236.28x10^3\ g)$$

$$= 23.63\ x10^3\ g$$

$$Solar\ EMERGY = (23.63\ x10^3\ g)(9.99x10^8 \frac{sej}{g})$$

$$= 2.36x10^{13}\ sej$$

Table HSPR-10: Component Production Phase E
Transformer

	Phase-E Component Production Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$126.37\ x10^{9}g$	$6.7\ x10^{9}$	$8.47\ x10^{20}sej$
E-1	Atmosphere			
E-2	Ecol. Prod.			
E-3	Energy			
E-4	Land			
E-5	Water			
E-6	Materials			
F	FUEL ENERGY	$18.05\ x10^{9}g$	$6.7\ x10^{9}$	$1.21\ x10^{20}sej$
F-1	Equipment			
F-2	Facilities			
F-3	Materials			
G	GOODS	$18.05\ x10^{9}g$	$6.7\ x10^{9}$	$1.21\ x10^{20}sej$
G-1	Equipment			
G-2	Facilities			
G-3	Goods			
G-4	Tools			
S	SERVICES	$18.05\ x10^{9}g$	$6.7\ x10^{9}$	$1.21\ x10^{20}sej$
S-1	Labor			
S-2	Materials			

Table HSPR-10: Component Production Phase E
Transformer

Material: Machinery

Machinery transformity = $6.7\ x10^{9}$ sej/g

Transformer Components:

Mass $= (398\ x10^{6}\ pounds)(453.6\frac{g}{Lb})$

$= 180.53\ x10^{9} g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(180.53\ x10^{9} g)$$

$$= 126.37\ x10^{9}\ g$$

$$Solar\ EMERGY = (126.37x10^{9} g)(6.7x10^{9}\frac{sej}{g})$$

$$= 8.47x10^{20}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(180.53x10^{9} g)$$

$$= 18.05\ x10^{9}\ g$$

$$Solar\ EMERGY = (18.05x10^{9} g)(6.70x10^{9}\frac{sej}{g})$$

$$= 1.21x10^{20}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(180.53x10^{9} g)$$

$$= 18.05\ x10^{9}\ g$$

$$Solar\ EMERGY = (18.05x10^9 g)(6.70x10^9 \frac{sej}{g})$$

$$= 1.21x10^{20}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(180.53x10^9 g)$$

$$= 18.05\ x10^9\ g$$

$$Solar\ EMERGY = (18.05x10^9 g)(6.70x10^9 \frac{sej}{g})$$

$$= 1.21x10^{20}\ sej$$

Table HSPR-11: Component Production Phase E Reactor

	Phase-E Component Production Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$76.20\ x10^{6}g$	$6.7\ x10^{9}$	$5.11\ x10^{17}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$10.89\ x10^{6}g$	$6.7\ x10^{9}$	$7.30\ x10^{16}sej$
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$10.89\ x10^{6}g$	$6.7\ x10^{9}$	$7.30\ x10^{16}sej$
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	$10.89\ x10^{6}g$	$6.7\ x10^{9}$	$7.30\ x10^{16}sej$
S-1	Labor	N/A		
S-2	Materials	N/A		

Table HSPR-11: Component Production Phase E
Reactor

Material: machinery

Machinery transformity $= 6.7\ x10^9 \frac{sej}{g}$

Reactor components:

Mass $= (240\ x10^3\ pounds)(453.6 \frac{g}{Lb})$

$= 108.86\ x10^6 g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(108.86x10^6 g)$$

$$= 76.20\ x10^6\ g$$

$$Solar\ EMERGY = (76.20x10^6 g)(6.7x10^9 \frac{sej}{g})$$

$$= 5.11x10^{17}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(108.86x10^6 g)$$

$$= 10.89\ x10^6\ g$$

$$Solar\ EMERGY = (10.89x10^6 g)(6.7x10^9 \frac{sej}{g})$$

$$= 7.30x10^{16}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(108.86x10^6 g)$$

$$= 10.89\ x10^6\ g$$

$$Solar\ EMERGY = (10.89x10^6 g)(6.7x10^9 \frac{sej}{g})$$

$$= 7.30x10^{16}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(108.86x10^{6}g)$$

$$= 10.89\ x10^{6}\ g$$

$$Solar\ EMERGY = (10.89x10^{6}g)(6.7x10^{9}\frac{sej}{g})$$

$$= 7.30x10^{16}\ sej$$

Table HPSR-12: Construction Phase F
Clearing and Grubbing

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$6.64\ x10^{11}\ J$		$4.38\ x10^{16}\ sej$
F-1	Equipment	$6.64\ x10^{11}\ J$	$6.6\ x10^{4}$	$4.38\ x10^{16}\ sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$6.73\ x10^{5} g$		$4.51\ x10^{15} sej$
G-1	Equipment	$6.73\ x10^{5} g$	$6.7\ x10^{9}$	$4.51\ x10^{15} sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	41,513.08$		$8.30\ x10^{16} sej$
S-1	Labor	41,513.08$	$2.0\ x10^{12}$	$8.30\ x10^{16} sej$
S-2	Materials	N/A		

Table HPSR-12: Construction Phase F
Clearing and Grubbing

$Area = (100\ ft)(5{,}280\ ft)$

$= 5.28\ x10^5 sf\left(\frac{1\ Acre}{43{,}560\ sf}\right)$

$= 12.12\ Acres$

$Duration = (12.12\ Acres)\left(\frac{1\ day}{0.7\ Acres}\right)$

$= 17.3\ days\ \left(8\ \frac{hours}{day}\right)$

$= 138.4\ hours$

Crew type is B-7 Modified

1-Labor foreman$ 37.45 per hour

4-Laborer $ 35.45 per hour

1-Equipment Operator $ 47.50

2-Truck Drivers $ 36.60

Equipment type

2-Dump Trucks (25,000 pounds)

1-Brush Chipper 130 HP (6,907 pounds)

1-Track Loader 3 CY (44,577 pounds)

2-Chain Saws 36 Inch Bar (23 pounds)

Environment

E5. No Water Usage

Fuel Energy

Petroleum Transformity $= 6.6x10^4\ \frac{sej}{J}$

F1. Equipment

F1.1Two Dump Trucks 25,000 lbs.
Fuel consumption = 8 gal/hour

$$Raw\ Units = (2)(8\ \frac{gal}{hour})(138.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 3.31\ x10^{11}J$

$$Solar\ EMERGY = (3.31x10^{11}J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 2.18x10^{16}\ sej$

F1.2 One Brush Chipper 130 HP

Fuel consumption = 7 gal/hour

Use = 138.4 hours

$$Raw\ Units = (7\ \frac{gal}{hour})(138.4\ hours)(\frac{barrel}{42\ gal})(6.28x10^9\ \frac{J}{barrel})^1$$

$= 1.45x10^{11}J$

$$Solar\ EMERGY = (1.45x10^{11}J)(6.6x10^4\ \frac{sej}{J})$$

$= 9.57\ x10^{15}sej$

F1.3 One Track Loader 3 CY

Fuel consumption = 7.7 gal/hour

Use = 138.4 hours

$$Raw\ Units = (7.7\ \frac{gal}{hour})(138.4\ hours)(\frac{barrel}{42\ gal})(6.28x10^9\ \frac{J}{barrel})^1$$

$= 1.59x10^{11}J$

$$Solar\ EMERGY = (1.59x10^{11}J)(6.6x10^4\ \frac{sej}{J})$$

$= 1.05\ x10^{16}sej$

F1.4 Two Chain Saws 36 inch

Fuel consumption = 0.7 gal/hour

Use = 138.4 hours

$$Raw\ Units = (2)(0.7\ \frac{gal}{hour})(138.4\ hours)(\frac{barrel}{42\ gal})(6.28x10^9\ \frac{J}{barrel})^1$$

$= 28.97x10^9J$

$$Solar\ EMERGY = (28.97x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= 1.91x10^{15} sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Two Dump Trucks

Weight = 25,000 LB Each

Useful Life = 10,000 hours

Use = 138.4 hours

$$Raw\ Units = 2(138.4\ hours)\left(\frac{1}{10,000\ hours}\right)(25,000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 3.14x10^5 g$

$$Solar\ EMERGY = (3.14x10^5 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 2.10\ x10^{15} sej$$

G1.2 One Brush Chipper (130 HP)

Weight = 6,907 LB

Useful Life = 6,000 hours

Use = 138.4 hours

$$Raw\ Units = (138.4\ hours)\left(\frac{1}{6,000\ hours}\right)(6,907\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 72.27x10^3 g$

$$Solar\ EMERGY = (72.27x10^3 g)(6.7\ x10^9\ sej/g)$$

$$= 4.84\ x10^{14} sej$$

G1.3 One Track Loader 3 CY

Weight = 44,577 LB

Useful Life = 10,000 hours

Use = 138.4 hours

$$Raw\ Units = (138.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(44{,}577\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 27.98x10^{4}g$

$$Solar\ EMERGY = (27.98x10^{4}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.87\ x10^{15} se\ j$$

G1.4 Two Chain Saws 36 Inch

Weight = 23 LB

Useful Life = 400 hours

Use = 138.4 hours

$$Raw\ Units = (2)(138.4\ hours)\left(\frac{1}{400\ hours}\right)(23\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$=7.22x10^{3}g$

$$Solar\ EMERGY = (7.22x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 4.84\ x10^{13} se\ j$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 138.4

Salary = $ 37.45

$$Raw\ Units = (\frac{\$\ 37.45}{hour})\ (138.4\ \text{hours})$$

=5,183.08$

$Solar\ EMERGY = (5{,}183.08\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 1.04\ x10^{16} se\ j$

S1.2 Four Laborers

Labor Hours = 138.4

Salary = $ 35.45

$Raw\ Units = 4(\frac{\$\ 35.45}{hour})\ (138.4\ \text{hours})$

$=19{,}625.12\$$

$Solar\ EMERGY = (19{,}625.12\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=3.93\ x10^{16} se\ j$

S1.3 One Equipment Operator

Labor Hours = 138.4

Salary = $ 47.50

$Raw\ Units = (\frac{\$\ 47.50}{hour})\ (138.4\ \text{hours})$

$=6{,}574.00\$$

$Solar\ EMERGY = (\ 6{,}574.00\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 1.31\ x10^{16} se\ j$

S1.4 Two Truck Drivers

Labor Hours = 138.4

Salary = $ 36.60

$Raw\ Units = (2)(\frac{\$\ 36.60}{hour})\ (138.4\ \text{hours})$

=10,130.88$

$$Solar\ EMERGY = (10{,}130.88\$)(2.00\ x10^{12}\frac{sej}{\$})$$

$$= 2.03\ x10^{16} sej$$

Table HPSR-13: Construction Phase F
Top Soil Stripping and Stockpiling

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$90.97\ x10^{9}J$		$6.00\ x10^{15}sej$
F-1	Equipment	$90.97\ x10^{9}J$	$6.6\ x10^{4}$	$6.00\ x10^{15}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$114.97\ x10^{3}g$		$7.70\ x10^{14}\ sej$
G-1	Equipment	$114.97\ x10^{3}g$	$6.7\ x10^{9}$	$7.70\ x10^{14}\ sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	3,391.70$		$6.78\ x10^{15}$
S-1	Labor	3,391.70$	$2.00\ x10^{12}$	$6.78\ x10^{15}$
S-2	Materials	N/A		

Table HPSR-13: Construction Phase F
Top Soil Stripping and Stockpiling

$$Volume = (1ft)(100\ ft)(5{,}280\ ft)$$

$$= 5.28x10^5 cf\ (\frac{1\ CY}{27\ cf})$$

$$= 19{,}556\ CY$$

$$Duration = (19{,}556\ CY)(\frac{1\ day}{3{,}000\ CY})$$

$$= 6.5\ days\ (\ 8\frac{hours}{day})$$

$$= 52\ hours$$

Crew type is B-10M

1-Equipment Operator $ 47.50

1/2-Laborer $ 35.45 per hour

Equipment type

1-Dozer 300 HP

Environment

E5. No Water Usage

Fuel Energy

Petroleum Transformity = $6.6x10^4\ \frac{sej}{J}$

F1. Equipment

F1.1 One Dozer (87,733 Lbs.)

Fuel consumption = 11.7 gal/hour

$$Raw\ Units = (11.7\ \frac{gal}{hour})(52\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 90.97\ x10^9 J$$

$$Solar\ EMERGY = (90.97\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 6.00x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 One Dozer 300 HP

Weight = 87,733 Lbs.

Useful Life = 18,000 hours

Use = 52 hours

$$Raw\ Units = (52\ hours)\left(\frac{1}{18{,}000\ hours}\right)(87{,}733\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 114.97x10^{3}g$$

$$Solar\ EMERGY = (114.97x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 7.7\ x10^{14}sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 52

Salary = $ 47.50

$$Raw\ Units = (\frac{\$\ 47.50}{hour})\ (52\ \text{hours})$$

=2,470.00$

$$Solar\ EMERGY = (2{,}470.00\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

$$= 4.94\ x10^{15}se\ j$$

S1.2 Laborer-(1/2)

Labor Hours = 26

Salary = $ 35.45

$Raw\ Units = (\frac{\$\ 35.45}{hour})$ (26 hours)

=921.70$

$Solar\ EMERGY = (921.70\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=1.84\ x10^{15} se\ j$

Table HPSR-14: Construction Phase F
Rough Grading

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT		N/A	
E-1	Atmosphere		N/A	
E-2	Ecol. Prod.		N/A	
E-3	Energy		N/A	
E-4	Land		N/A	
E-5	Water		N/A	
E-6	Materials		N/A	
F	FUEL ENERGY	$105.26x10^9 J$		$6.95x10^{15} sej$
F-1	Equipment	$105.26x10^9 J$	$6.6x10^4$	$6.95x10^{15} sej$
F-2	Facilities		N/A	
F-3	Materials		N/A	
G	GOODS	$169.85x10^3 g$		$1.14x10^{15} sej$
G-1	Equipment	$169.85x10^3 g$	$6.7x10^9$	$1.14\ x10^{15} sej$
G-2	Facilities			
G-3	Goods			
G-4	Tools			
S	SERVICES	11,679.36$		$2.34x10^{16} sej$
S-1	Labor	11,679.36$	$2.00x10^{12}$	$2.34x10^{16} sej$
S-2	Materials			

Table HPSR-14: Construction Phase F
Rough Grading

$Area = (100\ ft)(5{,}280\ ft)$

$= (5.28\ x10^5 sf\ )$

$Duration = (5.28\ x10^5 sf)(\frac{1\ day}{30{,}000\ sf})$

$= 17.6\ days\ (8\ \frac{hours}{day})$

$= 140.8\ hours$

Crew type is B-11L

1-Equipment Operator $ 47.50 per hour

1-Laborer $ 35.45 per hour

Equipment type

1-Grader (39,892 pounds)

Environment

E5. No Water Usage

Fuel Energy

Petroleum Transformity = $6.6x10^4\ \frac{sej}{J}$

F1. Equipment

F1.1 One Grader (39,982 Lbs.)

Fuel consumption = 5.0 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(140.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 105.26\ x10^9 J$$

$$Solar\ EMERGY = (105.26\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 6.95x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Grader

Weight = 39,892 Lbs.

Useful Life = 15,000 hours

Use = 140.8 hours

$$Raw\ Units = (140.8\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}892LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 169.85x10^{3}g$$

$$Solar\ EMERGY = (169.85x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.14\ x10^{15}sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 140.8

Salary = \$ 47.50

$$Raw\ Units = (\frac{\$\ 47.50}{hour})\ (140.8\ \text{hours})$$

=6,688.00\$

$$Solar\ EMERGY = (6{,}688.00\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$$

$$= 1.34\ x10^{16}se\ j$$

S1.2 One Laborer

Labor Hours = 140.8

Salary = \$ 35.45

$$Raw\ Units = (\frac{\$\ 35.45}{hour})\ (140.8\ \text{hours})$$

=4,991.36$

$$Solar\ EMERGY = (4{,}991.36\$)(2.00\ x10^{12}\ \frac{sej}{\$})$$

$$=9.98\ x10^{15} se\ j$$

Table HPSR-15: Construction Phase F
Fine Grading

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$2.60x10^{8}J$		$1.73x10^{14}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$2.60x10^{8}J$	$6.66x10^{5}$	$1.73x10^{14}sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$2.38x10^{11}J$		$1.57x10^{16}sej$
F-1	Equipment	$2.38x10^{11}J$	$6.6x10^{4}$	$1.57x10^{16}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$3.47x10^{5}g$		$2.32x10^{15}sej$
G-1	Equipment	$3.47x10^{5}g$	$6.7x10^{9}$	$2.32x10^{15}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	20,006.52$		$4.00x10^{16}sej$
S-1	Labor	20,006.52$	$2.0x10^{12}$	$4.00x10^{16}sej$
S-2	Materials	N/A		

Table HSPR-15: Construction Phase F
Fine Grading

Crew type is B-32C for fine grading

1-Labor Foreman $ 37.45

2-Laborer $ 35.45 per hour

3-Equipment Operator $ 47.50 per hour

1-Truck Driver $ 36.60

Equipment type

1-Grader (39,892 pounds)

1-Tandem Roller (23,525 pounds)

1-Dozer (48,588 Pounds)

1-Water Truck (25,000 pounds)

$$Duration = (52\ ft)(5{,}280\ ft)(\frac{1\ sy}{9\ sf})$$

$$= 30.51\ x10^3\ \ sy\ (\frac{1 day}{3{,}500\ sy})$$

$$= 8.7\ days(\frac{8\ hours}{day})$$

$$= 69.6\ hours$$

Environment

E5. Water

1,600 gal/day per roller

Volume= $(8.7\ days)(1{,}600\ \frac{gal}{day})$

$$= 13{,}920\ gallons$$

$$Raw\ Units = (13{,}920\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^1$$

$$= 260.30\ x10^6 J$$

$$Solar\ EMERGY = (260.30\ x10^6 J)(6.66x10^5 \frac{sej}{J})$$

$$= 1.73x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Grader (39,892 Lbs.)

Fuel consumption = 5.0 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(69.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 52.03\ x10^9 J$$

$$Solar\ EMERGY = (52.03\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= 3.43x10^{15}\ sej$$

F1.2 One Tandem Roller (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = (2.5\ \frac{gal}{hour})(69.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 26.02\ x10^9 J$$

$$Solar\ EMERGY = (26.02\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= 1.72x10^{15}\ sej$$

F1.3 One Dozer (48,588 Lbs.)

Fuel consumption = 7.4 gal/hour

$$Raw\ Units = (7.4\ \frac{gal}{hour})(69.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 77.01\ x10^9 J$$

$$Solar\ EMERGY = (77.01\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= 5.08x10^{15}\ sej$$

F1.4 One Water Truck (25,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(69.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$= 83.25\ x10^9 J$$

$$Solar\ EMERGY = (83.25\ x10^9 J)(6.6x10^4\frac{sej}{J})$$

$$= \ 5.49x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Grader

Weight = 39,982 Lbs.

Useful Life = 15,000 hours

Use = 69.6 hours

$$Raw\ Units = (69.6\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}982\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 84.15x10^3 g$$

$$Solar\ EMERGY = (84.15x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 5.64\ x10^{14} sej$$

G1.2 One Tandem Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 69.6 hours

$$Raw\ Units = (69.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 74.27x10^3 g$$

$$Solar\ EMERGY = (74.27x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 4.98\ x10^{14} sej$

G1.3 One Dozer

Weight = 48,588 Lbs.

Useful Life = 14,000 hours

Use = 69.6 hours

$$Raw\ Units = (69.6\ hours)\left(\frac{1}{14{,}000\ hours}\right)(48{,}588\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 109.57x10^3 g$

$$Solar\ EMERGY = (109.57x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 7.34x10^{14} sej$

G1.4 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 69.6 hours

$$Raw\ Units = (69.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 78.93x10^3 g$

$$Solar\ EMERGY = (78.93x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 5.29\ x10^{14} sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 69.6

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (69.6 hours)

=2,606.52$

$Solar\ EMERGY = (2{,}606.52\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 5.21\ x10^{15} se\ j$

S1.2 Two Laborers

Labor Hours = 69.6

Salary = $ 35.45

$Raw\ Units =\ (2)(\frac{\$\ 35.45}{hour})$ (69.6 hours)

=4,934.64$

$Solar\ EMERGY = (4{,}934.64\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=9.87\ x10^{15} se\ j$

S1.3 Three Equipment Operators

Labor Hours = 69.6

Salary = $ 47.50

$Raw\ Units = (3)(\frac{\$\ 47.50}{hour})$ (69.6 hours)

=9,918$

$Solar\ EMERGY = (9{,}918\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=1.98\ x10^{16} se\ j$

S1.6 One Truck Driver

Labor Hours = 69.6

Salary = \$ 36.60

$Raw\ Units = \left(\frac{\$\ 36.60}{hour}\right)$ (69.6 hours)

=2,547.36\$

$Solar\ EMERGY = (2{,}547.36\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=5.09\ x10^{15} se\ j$

Table HSPR-16: Construction Phase F
Subballast 6 Inch Aggregate Base Course

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$2.71x10^{8}J$		$1.81x10^{14}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$2.71x10^{8}J$	$6.66x10^{5}$	$1.81x10^{14}sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$8.24x10^{11}J$		$5.44x10^{16}sej$
F-1	Equipment	$8.24x10^{11}J$	$6.6x10^{4}$	$5.44x10^{16}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$8.54x10^{5}g$		$5.72x10^{15}sej$
G-1	Equipment	$8.54\ x10^{5}g$	$6.7x10^{9}$	$5.72x10^{15}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	28,998.84$		$5.80x10^{16}sej$
S-1	Labor	28,998.84$	$2.00x10^{12}$	$5.80x10^{16}sej$
S-2	Materials	N/A		

Table HSPR-16: Construction Phase F
Subballast 6 Inch Aggregate Base Course

Material: Aggregate

Stone (mined) transformity = $1.00\ x10^9$ sej/g

Stone specific weight (compacted) = 3,180 lb/CY

Specific weight compacted = 3180 lb/cy

Volume $= (30\ ft)(5{,}280\ ft)^1(\frac{6}{12} ft)\left(\frac{1CY}{27\ CF}\right)$

$= 2{,}933.3\ CY$

Mass $= (2{,}933.3\ CY)\left(\frac{3{,}180\ lb}{CY}\right)(\frac{1\ Ton}{2{,}000\ lb})$

$= \ 4{,}664\ tons$

Compaction Rate $= \frac{1{,}000\ CY}{Day}$

Duration $= 2{,}933.3\ CY(\frac{1\ day}{1{,}000\ CY})$

$= 2.9\ days(\frac{8\ hours}{Day})$

$= 23.2\ hours$

Hauling Duration $= 4{,}664\ tons(\frac{1\ trip}{16\ tons})$

$= say\ 292\ truck\ round\ trips$

$= \frac{292\ trips}{2.9\ days}$

$= \frac{100\ trips}{day}$

Each round trip is ~ 20 miles and takes ~ 2 hours. Therefore a truck can make 4 trips a day, so use 25 trucks.

Crew type is B-36B Modified

1-Labor Foreman \$ 37.45

2-Laborers \$ 35.45 per hour

26-Truck Drivers \$ 36.60 per hour

4-Equipment Operator \$ 47.50 per hour

Equipment type

1-Grader (39,892 pounds)

1-Front End Track Loader (44,577 pounds)

1-Dozer (87,733 pounds)

1-Roller (41,214 pounds)

1-Water Truck (25,000 pounds)

25-Dump Trucks (25,000 pounds)

Environment

E5. Water

E.5.1: (1) Water Truck 5,000 $\frac{gal}{day}$

Volume= $(2.9\ days)(5{,}000\ \frac{gal}{day})$

$= 14{,}500\ gallons$

$$Raw\ Units = (14{,}500\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$$

$$= 271.15\ x10^{6} J$$

$$Solar\ EMERGY = (271.15\ x10^{6} J)(6.66x10^{5}\ \frac{sej}{J})$$

$$= \ 1.81x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity $= 6.6x10^{4}\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Grader (39,892 Lbs.)

Fuel consumption = 5.0 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(23.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 17.34\ x10^9 J$$

$$Solar\ EMERGY = (17.34\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 1.14x10^{15}\ sej$$

F1.2 One Front End Track Loader (44,577 Lbs.)

Fuel consumption = 7.7 gal/hour

$$Raw\ Units = (7.7\ \frac{gal}{hour})(23.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 26.71\ x10^9 J$$

$$Solar\ EMERGY = (26.71\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 1.76x10^{15}\ sej$$

F1.3 One Dozer (87,733 Lbs.)

Fuel consumption = 11.7 gal/hour

$$Raw\ Units = (11.7\ \frac{gal}{hour})(23.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 40.59\ x10^9 J$$

$$Solar\ EMERGY = (40.59x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 2.68x10^{15}\ sej$$

F1.4 One Roller (42,214 Lbs.)

Fuel consumption = 5 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(23.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 17.34\ x10^9 J$$

$$Solar\ EMERGY = (17.34\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 1.14x10^{15}\ sej$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(23.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$= 27.75\ x10^{9}J$

$$Solar\ EMERGY = (27.75\ x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$$

$= \ 1.83x10^{15}\ sej$

F1.6 Twenty Five Dump Trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (25)(8\ \frac{gal}{hour})(23.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$= 693.79\ x10^{9}J$

$$Solar\ EMERGY = (693.79\ x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$$

$= \ 4.58x10^{16}\ sej$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 One Grader

Weight = 39,982 Lbs.

Useful Life = 15,000 hours
Use = 23.2 hours

$$Raw\ Units = (23.2\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}982\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 28.05x10^{3}g$

$$Solar\ EMERGY = (28.05x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 1.88\ x10^{14}sej$

G1.2 One Front-end Track Loader

Weight = 44,577 Lbs.

Useful Life = 10,000 hours

Use = 23.2 hours

$$Raw\ Units = (23.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(44{,}577\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 46.91x10^{3}g$$

$$Solar\ EMERGY = (46.91x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 3.14\ x10^{14}sej$$

G1.3 One Dozer

Weight = 87,733 Lbs.

Useful Life = 18,000 hours

Use = 23.2 hours

$$Raw\ Units = (23.2\ hours)\left(\frac{1}{18{,}000\ hours}\right)(87{,}733\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 51.29x10^{3}g$$

$$Solar\ EMERGY = (51.29x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 3.44\ x10^{14}sej$$

G1.4 One Roller

Weight = 41,214 Lbs.

Useful Life = 10,000 hours

Use = 23.2 hours

$$Raw\ Units = (23.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(41{,}214\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 43.37x10^{3}g$$

$$Solar\ EMERGY\ = (43.37x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 2.91\ x10^{14} sej$$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 23.2 hours

$$Raw\ Units\ = (23.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 26.31x10^3 g$$

$$Solar\ EMERGY\ = (26.31x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.76x10^{14} sej$$

G1.6 Twenty Five Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 23.2 hours

$$Raw\ Units\ = (25)(23.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 657.72x10^3 g$$

$$Solar\ EMERGY\ = (657.72x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 4.41x10^{15} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 23.2

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (23.2 hours)

=868.84$

$Solar\ EMERGY = (868.84\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

= 1.74 $x10^{15} se\ j$

S1.2 Two Laborers

Labor Hours = 23.2

Salary = $ 35.45

$Raw\ Units = (2)(\frac{\$\ 35.45}{hour})$ (23.2 hours)

=1,644.88$

$Solar\ EMERGY = (1{,}644.88\$)(2.00\ x10^{12}\frac{sej}{\$})$

=3.29 $x10^{15} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 23.2

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$\ 47.50}{hour})$ (23.2 hours)

=4,408$

$Solar\ EMERGY = (4{,}408\$)(2.00\ x10^{12}\frac{sej}{\$})$

=8.82 $x10^{15} se\ j$

S1.4 Twenty Six Truck Drivers

Labor Hours = 23.2

Salary = \$ 36.60

$Raw\ Units = (26)(\frac{\$\ 36.60}{hour})$ (23.2 hours)

=22,077.12\$

$Solar\ EMERGY = (22{,}077.12\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=4.42\ x10^{16} se\ j$

Table HPSR-17: Construction Phase F
Ballast

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$8.23x10^8 J$		$5.48x10^{14} sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$8.23x10^8 J$	$6.66x10^5$	$5.48x10^{14} sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$2.08x10^{12} J$		$1.37x10^{17} sej$
F-1	Equipment	$2.08\ x10^{12} J$	$6.6x10^4$	$1.37x10^{17} sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.13x10^6 g$		$1.43x10^{16} sej$
G-1	Equipment	$2.13\ x10^6 g$	$6.7x10^9$	$1.43x10^{16} sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	77,689.92$		$1.55x10^{17} sej$
S-1	Labor	77,689.92$	$2.00x10^{12}$	$1.55x10^{17} sej$
S-2	Materials	N/A		

Table HPSR-17: Construction Phase F
Ballast

Material: Railroad Aggregate

Stone (mined) transformity = $1.00\ x10^9$ sej/g

Stone specific weight (compacted) = 2,719 lb/CY

$$\text{Volume} = 30\ ft\left(12\ in\ *\ \frac{1ft}{12\ in}\right)(5{,}280\ ft)^1\left(\frac{1CY}{27\ CF}\right)$$

$$= 5{,}866.7\ CY$$

$$\text{Volume} = 30\ ft\left(6\ in\ *\ \frac{1ft}{12\ in}\right)(5{,}280\ ft)^1\left(\frac{1CY}{27\ CF}\right)$$

$$= 2{,}933.3\ CY$$

$$\text{Mass} = 8{,}800\ CY\left(\frac{2{,}719\ lb}{CY}\right)\left(\frac{TN}{2{,}000\ lb}\right)$$

$$= 11.96\ x10^3\ TN$$

$$\text{Compaction Rate} = \frac{1{,}000\ CY}{Day}$$

$$\text{Duration} = 8{,}800\ CY\left(\frac{1\ Day}{1{,}000\ CY}\right)$$

$$= 8.8\ days\left(\frac{8\ hours}{Day}\right)$$

$$= 70.4\ hours$$

$$\text{Hauling Duration} = 11.96\ x10^3\ TN\left(\frac{1\ trip}{16\ Tons}\right)$$

$$= say\ 748\ trips$$

$$= \frac{748\ trips}{8.8\ days}$$

$$= \frac{85\ trips}{day}$$

Each round trip is ~ 20 miles and takes ~ 2 hours. Therefore a truck can make 4 trips a day, so use 21 trucks.

Crew type is B-36B Modified

1-Labor Foreman $ 37.45

2-Laborers $ 35.45 per hour

4-Equipment Operator $ 47.50 per hour

22-Truck Drivers $ 36.60 per hour

Equipment type

1-Grader (39,892 pounds)

1-Dozer (87,733 pounds)

1-Roller (41,214 pounds)

1-Water Truck (25,000 pounds)

21-Dump Trucks (25,000 pounds)

Environment

E5. Water

E.5.1: (1) Water Truck 5,000 $\frac{gal}{day}$

$$\text{Volume}= (8.8\ days)(5{,}000\ \frac{gal}{day})$$

$$= 44{,}000\ gallons$$

$$Raw\ Units = (44{,}000\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$$

$$= 822.79\ x10^{6} J$$

$$Solar\ EMERGY = (822.79\ x10^{6} J)(6.66x10^{5}\ \frac{sej}{J})$$

$$= \ 5.48x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Grader (39,892 Lbs.)

Fuel consumption = 5.0 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(70.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 52.63\ x10^9 J$$

$$Solar\ EMERGY = (52.63\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 3.47x10^{15}\ sej$$

F1.2 One Dozer (87,733 Lbs.)

Fuel consumption = 11.7 gal/hour

$$Raw\ Units = (11.7\ \frac{gal}{hour})(70.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 123.16\ x10^9 J$$

$$Solar\ EMERGY = (123.16x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 8.13x10^{15}\ sej$$

F1.3 One Roller (42,214 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(70.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 52.63\ x10^9 J$$

$$Solar\ EMERGY = (52.63\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 3.47x10^{15}\ sej$$

F1.4 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(70.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 84.21\ x10^9 J$$

$$Solar\ EMERGY = (84.21\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 5.56x10^{15}\ sej$$

F1.5 Twenty One Dump Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (21)(8\ \frac{gal}{hour})(70.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 1.77\ x10^{12} J$$

$$Solar\ EMERGY = (1.77\ x10^{12} J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 1.17x10^{17}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Grader

Weight = 39,982 Lbs.

Useful Life = 15,000 hours

Use = 70.4 hours

$$Raw\ Units = (70.4\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}982\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 85.12x10^3 g$$

$$Solar\ EMERGY = (85.12x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 5.70\ x10^{14} sej$$

G1.2 One Dozer

Weight = 87,733 Lbs.

Useful Life = 18,000 hours

Use = 70.4 hours

$$Raw\ Units = (70.4\ hours)\left(\frac{1}{18{,}000\ hours}\right)(87{,}733\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 155.65x10^{3}g$$

$$Solar\ EMERGY = (155.65x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.04\ x10^{15}sej$$

G1.3 One Roller

Weight = 41,214 Lbs.

Useful Life = 10,000 hours

Use = 70.4 hours

$$Raw\ Units = (70.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(41{,}214\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 131.61x10^{3}g$$

$$Solar\ EMERGY = (131.61x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 8.82\ x10^{14}sej$$

G1.4 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 70.4 hours

$$Raw\ Units = (70.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 79.83x10^{3}g$$

$$Solar\ EMERGY = (79.83x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.35x10^{14}sej$$

G1.5 Twenty One Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 70.4 hours

$Raw\ Units = (21)(70.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 1.68x10^{6}g$

$Solar\ EMERGY = (1.68x10^{6}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 1.13x10^{16}sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 70.4

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (70.4 hours)

=2,636.48$

$Solar\ EMERGY = (2{,}636.48\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 5.27\ x10^{15}se\ j$

S1.2 Two Laborers

Labor Hours = 70.4

Salary = $ 35.45

$Raw\ Units = (2)(\frac{\$\ 35.45}{hour})$ (70.4 hours)

=4,991.36$

$Solar\ EMERGY = (4{,}991.36\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$9.98\ x10^{15} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 70.4

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$\ 47.50}{hour})$ (70.4 hours)

=13,376$

$Solar\ EMERGY = (13{,}376\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$2.68\ x10^{16} se\ j$

S1.4 Twenty Two Truck Drivers

Labor Hours = 70.4

Salary = $ 36.60

$Raw\ Units = (22)(\frac{\$\ 36.60}{hour})$ (70.4 hours)

=56,686.08$

$Solar\ EMERGY = (56{,}686.08\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.13\ x10^{17} se\ j$

Table HPSR-18: Construction Phase F
Concrete Rail Ties

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$1.02x10^{12}J$		$6.75x10^{16}sej$
F-1	Equipment	$1.02x10^{12}J$	$6.6x10^4$	$6.75\ x10^{16}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.22x10^6g$		$1.49x10^{16}sej$
G-1	Equipment	$2.22x10^6g$	$6.7x10^9$	$1.49x10^{16}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	152,416.80$		$3.05x10^{17}sej$
S-1	Labor	152,416.80$	$2.00x10^{12}$	$3.05\ x10^{17}sej$
S-2	Materials	N/A		

Table HPSR-18: Construction Phase F
Concrete Rail Ties

Material: Concrete Ties

Concrete ties placed 24 inches center to center with double tracks.

$$Quantity = (2)(\frac{5{,}280\ ft}{2\ ft})$$

$$= 5{,}280\ ties$$

$$\text{Rate} = (5{,}280\ ties)(\frac{1\ day}{80\ ties})$$

$$= (66\ days)(\frac{8\ hours}{day})$$

$$= 528\ hours$$

Semi-truck hauls 51 ties per load (51) (780 Lbs.) ~ 40,000 Pounds

Haul distance is 20 miles round trip at 2 hours per trip or 4 trips per day per truck

Use four trucks at 816 ties/day or $\frac{5{,}280\ Ties}{816\ Ties/day}$ = 6.5 days or 52 hours

Crew type is B-14 Modified

1-Labor Foreman $ 37.45

4-Laborers $ 35.45 per hour

2-Equipment Operators $ 47.50 per hour

4-Truck Drivers $ 36.60

Equipment type

1-Back Hoe Loader (24,251 pounds)

1-Hydraulic Excavator (54,660 pounds)

4-Semi Tractor/Trailers (35,000 pounds)

Environment

E5. Water

E.5 No Water Usage

Fuel Energy

Petroleum Transformity = $6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Back Hoe Loader (24,251Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (3.5\ \frac{gal}{hour})(528\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$=276.32x10^9 J$$

$$Solar\ EMERGY = (276.32\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$=\ 1.82x10^{16}\ sej$$

F1.2 One Hydraulic Excavator (54,660Lbs.)

Fuel consumption = 6.3 gal/hour

$$Raw\ Units = (6.3\ \frac{gal}{hour})(528\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$=497.38x10^9 J$$

$$Solar\ EMERGY = (497.38\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$=\ 3.28x10^{16}\ sej$$

F1.3 Four Semi-Trucks (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (4)(8\ \frac{gal}{hour})(52\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 248.81\ x10^9 J$$

$$Solar\ EMERGY = (248.81x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$=\ 1.64x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Back Hoe

Weight = 24,251 Lbs.

Useful Life = 10,000 hours

Use = 528 hours

$$Raw\ Units = (528\ hours)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 580.81x10^{3}g$

$$Solar\ EMERGY = (580.81x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 3.89\ x10^{15}sej$$

G1.2 One Hydraulic Excavator

Weight = 54,660 Lbs.

Useful Life = 10,000 hours

Use = 528 hours

$$Raw\ Units = (528\ hours)\left(\frac{1}{10{,}000\ hours}\right)(54{,}660\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 1.31x10^{6}g$

$$Solar\ EMERGY = (1.31x10^{6}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 8.78\ x10^{15}sej$$

G1.3 Four Semi-Truck and Trailer

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 52 hours

$$Raw\ Units = (4)(52\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 330.22x10^{3}g$

$$Solar\ EMERGY = (330.22x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 2.21\ x10^{15} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 528

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (528 hours)

=19,773.60$

$$Solar\ EMERGY = (19{,}773.60\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

= 3.95 $x10^{16} se\ j$

S1.2 Four Laborers

Labor Hours = 528

Salary = $ 35.45

$Raw\ Units = (4)(\frac{\$\ 35.45}{hour})$ (528 hours)

=74,870.40$

$$Solar\ EMERGY = (74{,}870.40\$)(2.00\ x10^{12}\frac{sej}{\$})$$

=1.50 $x10^{17} se\ j$

S1.3 Two Equipment Operators

Labor Hours = 528

Salary = $ 47.50

$Raw\ Units = (2)(\frac{\$47.50}{hour})$ (528 hours)

=50,160.00$

$Solar\ EMERGY = (50{,}160.00\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

= $1.00\ x10^{17} se\ j$

S1.4 Four Truck Drivers

Labor Hours = 52

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$\ 36.60}{hour})$ (52 hours)

=7,612.80$

$Solar\ EMERGY = (7{,}612.80\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$1.52\ x10^{16} se\ j$

Table HPSR-19: Construction Phase F
136 Lb. Rail

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$1.98x10^{12}J$		$1.31x10^{17}sej$
F-1	Equipment	$1.98x10^{12}J$	$6.6x10^{4}$	$1.31x10^{17}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.99x10^{7}g$		$2.00x10^{17}sej$
G-1	Equipment	$2.99x10^{7}g$	$6.7x10^{9}$	$2.00x10^{17}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	204,606.92$		$4.09x10^{17}sej$
S-1	Labor	204,606.92$	$2.00x10^{12}$	$4.09x10^{17}sej$
S-2	Materials	N/A		

Table HPSR-19: Construction Phase F
136 Lb. Rail

Material: Steel Rail 140 Lb. /YD

Steel rail will be placed at a rate of 975 feet or 25 sections per day.

$Length = (4)\ (5{,}280\ ft)$

$= 21{,}120\ lf$ Or 542 sections of rail at ~ 39 feet per section

Rate = $(21{,}120\ lf)(\frac{1\ day}{975\ lf})$

$= (21.7\ days)(\frac{8\ hours}{day})$

$= 173.6\ hours$ To place rail

Semi-truck hauls 22 rail sections per load (22) (1,768 Lbs.) ~ 38,896 Pounds

Haul distance is 20 miles round trip at 2 hours per trip or 4 trips per day per truck

Use one truck at 88 rail sections/day or $\frac{542\ rail\ sections}{88\ rails/day}$ = 6.2 days or 49.6 hours

Welding Duration= $(548\ welds)(\frac{1.5\ hours}{weld})$

$= 822\ hours\ per\ weld\ crew$

$Use\ two\ crews\ so\ 411\ hours\ per\ crew$

Crew type is B-14 Modified

2-Labor Foreman $ 37.45

8-Laborers $ 35.45 per hour

4-Equipment Operators $ 47.50 per hour

1-Truck Driver $ 36.60

2-Welder Foreman $ 52.05

2-Welders $ 50.05

1-Engineer $ 60.00

1-Assistant Engineer $ 52.00

1-Herzog Plus Train Technician $ 47.50

1-Ballast Regulator Operator \$ 47.50

1-Tamper Operator - \$ 47.50

Equipment type

2-Back Hoe Loaders (24,251 pounds)

1-Semi Tractor/Trailer (35,000 pounds)

2-Hydraulic Excavators (54,660 pounds)

2-Rail Saws with Clamps (56 pounds)

2-Weld Shearers (100 pounds)

2-Upright Grinders (26 pounds)

2-Hydraulic Power Units (330 pounds)

2-Orgo-Thermit Tool Kits (155 pounds)

548-Orgo-Thermit Single Use Crucibles (77 pounds)

101-Oxygen/Acetylene Tanks (175 Pounds)

2-Work Trucks (8,000 Pounds)

1-Locomotive (250,000 pounds)

20-Herzog GPS Rail Cars (74,000 pounds)

1-Ballast Regulator (56,000 pounds)

1-Tamper (70,000 pounds)

Final Ballast= $(0.5\ ft)(30\ ft)(5280\ ft)\ (\frac{1\ CY}{27\ cf})\ (\frac{2{,}719\ Lbs.}{CY})$

$$= 7.98x10^6\ pounds$$

Each Herzog car hauls 100,000 pounds so:

$$= (7.98x10^6\ pounds)(\frac{1\ Herzog\ car}{100{,}000\ pounds})$$

$$= 79.8\ say\ 80\ cars$$

So 4 train loads at 20 cars each with a 20 mile round trip at 1 trip per day so:

$$= (80\ cars)(\frac{1\ day}{20\ cars})$$

$= 4 \text{ days}(\frac{8\ hours}{day})$

$= 32$ hours

Environment

E5. Water

E.5 No Water Usage

Fuel Energy

Petroleum Transformity $= 6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 Two Back Hoe Loaders (24,251Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (2)(3.5\ \frac{gal}{hour})(173.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$=181.70x10^9 J$$

$$Solar\ EMERGY = (181.70\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 1.20x10^{16}\ sej$$

F1.2 One Semi-Truck and Trailer (35,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(49.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 59.33\ x10^9 J$$

$$Solar\ EMERGY = (59.33x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 3.92x10^{15}\ sej$$

F1.3 Two Hydraulic Excavators (54,660 Lbs.)

Fuel consumption = 6.3 gal/hour

$$Raw\ Units = (2)(6.3\ \frac{gal}{hour})(173.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 327.06\ x10^9 J$$

$$Solar\ EMERGY = (327.06x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 2.16x10^{16}\ sej$$

F1.4 Two Hydraulic Power Units (330 Lbs.)

Fuel consumption = 1.3 gal/hour

$$Raw\ Units = (2)(1.3\ \frac{gal}{hour})(411\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 159.78\ x10^9 J$$

$$Solar\ EMERGY = (159.78x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 1.05x10^{16}\ sej$$

F1.5 Two Work Trucks (8,000 Lbs.)

Fuel consumption = 4 gal/hour

$$Raw\ Units = (2)(4\ \frac{gal}{hour})(411\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 491.63\ x10^9 J$$

$$Solar\ EMERGY = (491.63x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 3.24x10^{16}\ sej$$

F1.6 One Smart Train ($1.73x10^6$ Lbs.)

Fuel consumption = 150 gal/hour

$$Raw\ Units = \ (150\ \frac{gal}{hour})(32\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 717.71\ x10^9 J$$

$$Solar\ EMERGY = (717.71x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 4.74x10^{16}\ sej$$

F1.7 One Ballast Regulator (56,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = \ (8\ \frac{gal}{hour})(32\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 38.28\ x10^9 J$$

$Solar\ EMERGY = (38.28x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 2.53x10^{15}\ sej$

F1.8 One Ballast Tamper (70,000 Lbs.)

Fuel consumption = 10.5 gal/hour

$Raw\ Units = \ (10.5\ \frac{gal}{hour})(2\ miles)(\frac{1\ hour}{0.5\ miles})\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$

$= 6.28\ x10^9 J$

$Solar\ EMERGY = (6.28x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 4.14x10^{14}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Two Back Hoe Loaders

Weight = 24,251 Lbs.

Useful Life = 10,000 hours

Use = 173.6 hours

$Raw\ Units = (2)(173.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 381.93x10^3 g$

$Solar\ EMERGY = (381.93x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 2.56\ x10^{15} sej$

G1.2 One Semi-Truck and Trailer

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 49.6 hours

$$Raw\ Units = (49.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 78.74x10^{3}g$

$$Solar\ EMERGY\ = (78.74x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.28\ x10^{14}sej$$

G1.3 Two Hydraulic Excavators

Weight = 54,660 Lbs.

Useful Life = 10,000 hours

Use = 173.6 hours

$$Raw\ Units = (2)(173.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(54{,}660\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 860.84x10^{3}g$

$$Solar\ EMERGY\ = (860.84x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.77\ x10^{15}sej$$

G1.4 Two Hydraulic Rail Saws

Weight = 56 Lbs.

Useful Life = 5,760 hours

Use = 411 hours

$$Raw\ Units = (2)(411\ hours)\left(\frac{1}{5{,}760\ hours}\right)(56\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 3.63\ x10^{3}g$

$$Solar\ EMERGY\ = (3.63\ x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 2.43\ x10^{13}sej$$

G1.5 Two Weld Shearers

Weight = 100 Lbs.

Useful Life = 5,760 hours

Use = 411 hours

$$Raw\ Units = (2)(411\ hours)\left(\frac{1}{5{,}760\ hours}\right)(100\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 6.47\ x10^{3} g$$

$$Solar\ EMERGY = (6.47\ x10^{3} g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 4.33\ x10^{13} sej$$

G1.6 Two Upright Grinders

Weight = 26 Lbs.

Useful Life = 5,760 hours

Use = 411 hours

$$Raw\ Units = (2)(411\ hours)\left(\frac{1}{5{,}760\ hours}\right)(26\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 1.68\ x10^{3}\ g$$

$$Solar\ EMERGY = (1.68\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.13x10^{13} sej$$

G1.7 Two Hydraulic Power Units

Weight = 330 Lbs.
Useful Life = 3,840 hours

Use = 411 hours

$$Raw\ Units = (2)(411\ hours)\left(\frac{1}{3{,}840\ hours}\right)(330\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 32.04\ x10^{3}\ g$$

$$Solar\ EMERGY = (32.04\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 2.15\ x10^{14} sej$$

G1.8 Two Orgo-Thermit Tool Kits

Weight = 155 Lbs.

Useful Life = 1,920 hours

Use = 411 hours

$$Raw\ Units = (2)(411\ hours)\left(\frac{1}{1{,}920\ hours}\right)(155\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 30.10\ x10^{3}\ g$$

$$Solar\ EMERGY = (30.10\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 2.02\ x10^{14} sej$$

G1.9 (548) Orgo-Thermit Single Use Crucibles

Weight = 77 Lbs.

Useful Life = 0.5 hours

Use = 0.5 hours

$$Raw\ Units = (548)(0.5\ hours)\left(\frac{1}{0.5\ hours}\right)(77\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 19.14\ x10^{6}\ g$$

$$Solar\ EMERGY = (19.14\ x10^{6}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.28\ x10^{17} sej$$

G1.10 (101) Oxygen/Acetylene Tanks

Weight = 175 Lbs.

Useful Life = 8 hours

Use = 8 hours

$$Raw\ Units = (101)(8\ hours)\left(\frac{1}{8\ hours}\right)(175\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 8.02\ x10^{6}\ g$$

$$Solar\ EMERGY = (8.02\ x10^{6}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 5.37\ x10^{16} sej$

G1.11 (2) Work Trucks

Weight = 8,000 Lbs.

Useful Life = 5,760 hours
Use = 411 hours

$$Raw\ Units = (2)(411\ hours)\left(\frac{1}{5{,}760\ hours}\right)(8{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 517.86\ x10^{3}\ g$

$$Solar\ EMERGY = (517.86\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 3.47\ x10^{15} sej$

G1.12 One Locomotive

Weight = 250,000 Lbs.

Useful Life = 52,000 hours

Use = 32 hours

$$Raw\ Units = (32\ hours)\left(\frac{1}{52{,}000\ hours}\right)(250{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 69.78\ x10^{3}\ g$

$$Solar\ EMERGY = (69.78\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 4.68\ x10^{14} sej$

G1.13 (20) Herzog GPS Rail Cars

Weight = 74,000 Lbs.

Useful Life = 31,200 hours

Use = 32 hours

$$Raw\ Units = (20)(32\ hours)\left(\frac{1}{31{,}200\ hours}\right)(74{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 688.54 x10^{3}\ g$

$Solar\ EMERGY = (688.54\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$

$= 4.61\ x10^{15} sej$

G1.14 One Ballast Regulator

Weight = 56,000 Lbs.

Useful Life = 20,800 hours

Use = 32 hours

$Raw\ Units = \ (32\ hours)\left(\frac{1}{20{,}800\ hours}\right)(56{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 39.08 x10^3\ g$

$Solar\ EMERGY = (39.08\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$

$= 2.62\ x10^{14} sej$

G1.15 One Ballast Tamper

Weight = 70,000 Lbs.

Useful Life = 20,800 hours
Use = 4 hours

$Raw\ Units = \ (4\ hours)\left(\frac{1}{20{,}800\ hours}\right)(70{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 6.11 x10^3\ g$

$Solar\ EMERGY = (6.11\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$

$= 4.09\ x10^{13} sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12} \frac{sej}{\$}$

S1.1 Two Labor Foremen

Labor Hours = 173.6

Salary = $ 37.45

$Raw\ Units\ = (2)(\frac{\$37.45}{hour})$ (173.6 hours)

=13,002.64$

$Solar\ EMERGY\ = (13{,}002.64\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

$= 2.60\ x10^{16} se\ j$

S1.2 Six Laborers

Labor Hours = 173.6

Salary = $ 35.45

$Raw\ Units\ = (6)(\frac{\$\ 35.45}{hour})$ (173.6 hours)

=36,924.72$

$Solar\ EMERGY\ = (36{,}924.72\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=7.38\ x10^{16} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 173.6

Salary = $ 47.50

$Raw\ Units\ = (4)(\frac{\$\ 47.50}{hour})$ (173.6 hours)

=32,984.00$

$Solar\ EMERGY\ = (32{,}984.00\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=6.60\ x10^{16} se\ j$

S1.4 One Truck Driver

Labor Hours =49.60

Salary = $ 36.60

$Raw\ Units = (1)(\frac{\$\ 36.60}{hour})$ (49.6 hours)

=1,815.36$

$Solar\ EMERGY = (1{,}815.36\$)(2.00\ x10^{12}\frac{sej}{\$})$

=3.63 $x10^{15} se\ j$

S1.5 Two Welder Forman

Labor Hours =411

Salary = $ 52.05

$Raw\ Units = (2)(\frac{\$\ 52.05}{hour})$ (411 hours)

=42,785.10$

$Solar\ EMERGY = (42{,}785.10\$)(2.00\ x10^{12}\frac{sej}{\$})$

=8.56 $x10^{16} se\ j$

S1.6 Two Welders

Labor Hours =411

Salary = $ 50.05

$Raw\ Units = (2)(\frac{\$\ 50.05}{hour})$ (411 hours)

=41,141.10$

$Solar\ EMERGY = (41{,}141.10\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=8.23\ x10^{16} se\ j$

S1.7 Two Laborers

Labor Hours =411

Salary = $ 35.45

$Raw\ Units = (2)(\frac{\$\ 35.45}{hour})$ (411 hours)

=29,139.90$

$Solar\ EMERGY = (29{,}139.90\$)(2.00\ x10^{12} \frac{sej}{\$})$

$=5.82\ x10^{16} se\ j$

S1.8 One Locomotive Engineer

Labor Hours =32

Salary = $ 60.00

$Raw\ Units = (\frac{\$\ 60.00}{hour})$ (32 hours)

=1,920.00$

$Solar\ EMERGY = (1{,}920.00\$)(2.00\ x10^{12} \frac{sej}{\$})$

$=3.84\ x10^{15} se\ j$

S1.9 One Assistant Locomotive Engineer

Labor Hours =32

Salary = $ 52.00

$Raw\ Units = (\frac{\$\ 52.00}{hour})$ (32 hours)

=1,664.00$

$Solar\ EMERGY\ =(1{,}664.00\$)(2.00\ x10^{12}\frac{sej}{\$})$

=3.33 $x10^{15}se\ j$

S1.10 One Herzog GPS Rail Car Technician

Labor Hours =32

Salary = $ 47.50

$Raw\ Units\ =(\frac{\$\ 47.50}{hour})$ (32 hours)

=1,520.00$

$Solar\ EMERGY\ =(1{,}520.00\$)(2.00\ x10^{12}\frac{sej}{\$})$

=3.04 $x10^{15}se\ j$

S1.11 One Ballast Regulator Operator

Labor Hours =32

Salary = $ 47.50

$Raw\ Units\ =(\frac{\$\ 47.50}{hour})$ (32 hours)

=1,520.00$

$Solar\ EMERGY\ =(1{,}520.00\$)(2.00\ x10^{12}\frac{sej}{\$})$

=3.04 $x10^{15}se\ j$

S1.12 One Ballast Tamper Operator

Labor Hours =4

Salary = $ 47.50

$Raw\ Units\ =(\frac{\$\ 47.50}{hour})$ (4 hours)

=190.00$

$$Solar\ EMERGY = (190.00\$)(2.00\ x10^{12}\frac{sej}{\$})$$

$$=3.80\ x10^{14} se\ j$$

Table HSPR-20: Construction Phase F
Electrification

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$2.40x10^{8}J$		$1.60x10^{14}J$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$2.40x10^{8}J$	$6.66x10^{5}J$	$1.60x10^{14}J$
E-6	Materials	N/A		
F	FUEL ENERGY	$7.39x10^{12}J$		$4.88x10^{17}sej$
F-1	Equipment	$7.39x10^{12}J$	$6.6x10^{4}$	$4.88x10^{17}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$1.03x10^{7}g$		$6.90x10^{16}sej$
G-1	Equipment	$1.03x10^{7}g$	$6.7x10^{9}$	$6.90x10^{16}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	1,944,376.68$		$3.89x10^{18}sej$
S-1	Labor	1,944,376.68$	$2.00x10^{12}$	$3.89x10^{18}sej$
S-2	Materials	N/A		

Table HSPR-20: Construction Phase F
Electrification

Material:

30 ft. steel light poles= $\frac{(2)(5280\text{ ft})}{80\text{ ft}}$

$= 132\ light\ poles(500\,\frac{pounds}{pole})$

$= 66.0\ x10^3\ pounds$

Installation Rate $= 132\ light\ poles\ (\frac{2.6\ days}{pole})$

$= 343.2\ days$

Use 4 crews so installation duration is 85.8 days $(\frac{8\ hours}{day}) = 686.4\ hours$

Concrete base $= 1{,}800\,\frac{pounds}{pole}\,(132\ poles)$

$= 237.6\ x10^3\ pounds$ Concrete $(\frac{1\ CY}{4{,}050\ pounds})$

$= 58.7\ CY$

Aluminum Power Transmission Cable= $(8\ cables)(\frac{5{,}280\ ft}{cable})$

$= 42.24\ x10^3\ ft\ of\ cable$

$= 42.24\ x10^3\ ft\ (\frac{1{,}045\ pounds}{1{,}000\ ft})$

$= 44.14\ x10^3\ pounds$

Crew R-3 Modified

4(1)-Electrician Foreman $ 52.90

4(1)-Electrician $ 52.40

4(0.5) - Equipment Operator $ 48.80

Equipment

4(1)-S. P. Crane 4 x 4 (10,000 pounds)

4(1)-Wheel loader/backhoe (24,252 pounds)

Crew C-6 Modified

1-Outside Labor Foreman $ 37.45

4-Laborers \$ 35.45

1-Cement Finisher \$ 43.05

Transformer = $398\ x10^6\ pounds$

Reactor = $240\ x10^3\ pounds$

Construction duration is estimated at 4 months using 4 crews = $693.3\ hours$ per crew

Crew R-11 Modified

4(4)-Electrician Foreman \$ 52.90

4(4)-Electricians \$ 52.40

4(1)-Equipment Operator \$ 48.80

4(1)-Common Laborer \$ 35.45

(1)-Liebherr Mobile Crane Operator \$ 49.00

Equipment

4(1)-Crew Truck (8,000 pounds)

4(1)-Hydraulic Crane (24,000 pounds)

1- Wheel loader/backhoe (24,251 pounds)

1-Liebherr Mobile Crane LTM 1095-5.1 (132,000 pounds)

E5. Water

E.5 Water use = $237.6\ x10^3\ pounds$ concrete (0.45)

$$= (106.92\ x10^3\ pounds\ of\ water)(\frac{1\ Gal}{8.34\ Lbs})$$

$$= 12.82\ x10^3 gallons$$

$$Raw\ Units = (12.82\ x10^3 gallons)\left(3.7854\frac{l}{gal}\right)\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)$$

$$= 239.73x10^6 J$$

$$Solar\ EMERGY = (239.73x10^6 J)(6.66x10^5 \frac{sej}{J})$$

$$= \ 1.60x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity $= 6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 Four S. P. Crane 4 x 4 (10,000 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = (4)(2.5\ \frac{gal}{hour})(686.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$=1.03x10^{12}J$$

$$Solar\ EMERGY = (1.03\ x10^{12}J)(6.6x10^4\frac{sej}{J})$$

$$=\ 6.8x10^{16}\ sej$$

F1.2 Four Wheel Loader/Backhoes (24,251 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (4)(3.5\ \frac{gal}{hour})(686.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$= 1.44\ x10^{12}J$$

$$Solar\ EMERGY = (1.44x10^{12}J)(6.6x10^4\frac{sej}{J})$$

$$=\ 9.50x10^{16}\ sej$$

F1.3 Four Crew Trucks (8,000 Lbs.)

Fuel consumption = 4 gal/hour

$$Raw\ Units = (4)(4\frac{gal}{hour})(693.3\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$= 1.66\ x10^{12}J$$

$$Solar\ EMERGY = (1.66x10^{12}J)(6.6x10^4\frac{sej}{J})$$

$$=\ 1.10x10^{17}\ sej$$

F1.4 Four Hydraulic Cranes (24,000 Lbs.)

Fuel consumption = 4 gal/hour

$$Raw\ Units = (4)(4\ \frac{gal}{hour})(693.3\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$= 1.66\ x10^{12}J$$

$$Solar\ EMERGY = (1.66x10^{12}J)(6.6x10^{4}\frac{sej}{J})$$

$$= \ 1.10x10^{17}\ sej$$

F1.5 One wheel loader/backhoe (24,251 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (3.5\ \frac{gal}{hour})(693.3\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\frac{J}{barrel}\right)^{1}$$

$$= 362.83\ x10^{9}J$$

$$Solar\ EMERGY = (362.83x10^{9}J)(6.6x10^{4}\frac{sej}{J})$$

$$= \ 2.39x10^{16}\ sej$$

F1.5 One Liebherr Mobile Crane LTM 1095-5.1 (132,000 pounds)

Fuel consumption = 12 gal/hour

$$Raw\ Units = (12\ \frac{gal}{hour})(693.3\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\frac{J}{barrel}\right)^{1}$$

$$= 1.24\ x10^{12}J$$

$$Solar\ EMERGY = (1.24x10^{12}J)(6.6x10^{4}\frac{sej}{J})$$

$$= \ 8.18x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Four S. P. Cranes 4 x 4

Weight = 10,000 Lbs.

Useful Life = 15,000 hours

Use = 686.4 hours

$$Raw\ Units = (4)(686.4\ hours)\left(\frac{1}{15{,}000\ hours}\right)(10{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 830.27x10^{3}g$$

$$Solar\ EMERGY = (830.27x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 5.56\ x10^{15} sej$

G1.2 Four wheel loaders/back hoes)

Weight = 24,251 Lbs.

Useful Life = 10,000 hours

Use = 686.4 hours

$$Raw\ Units = (4)(686.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 3.02x10^{6} g$

$$Solar\ EMERGY = (3.02x10^{6} g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 2.02\ x10^{16} sej$

G1.3 Four Work Trucks

Weight = 10,000 Lbs.

Useful Life = 7,500 hours

Use = 693.3 hours

$$Raw\ Units = (4)(693.3\ hours)\left(\frac{1}{7{,}500\ hours}\right)(10{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 1.68x10^{6} g$

$$Solar\ EMERGY = (1.68x10^{6} g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 1.13\ x10^{16} sej$

G1.4 Four Hydraulic Cranes

Weight = 24,000 Lbs.

Useful Life = 15,000 hours

Use = 693.3 hours

$$Raw\ Units = (4)(693.3\ hours)\left(\frac{1}{15{,}000\ hours}\right)(24{,}000 LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 2.01\ x10^{6} g$

$Solar\ EMERGY = (2.01\ x10^6 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 1.35\ x10^{16} sej$

G1.5 One Wheel Loader/Backhoe

Weight = 24,251 Lbs.

Useful Life = 10,000 hours

Use = 693.3 hours

$Raw\ Units = (693.3\ hours)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 762.65\ x10^3 g$

$Solar\ EMERGY = (762.65\ x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 5.11\ x10^{15} sej$

G1.6 One Liebherr Mobile Crane LTM 1095-5.1

Weight = 132,000 Lbs.

Useful Life = 20,800 hours

Use = 693.3 hours

$Raw\ Units = (693.3\ hours)\left(\frac{1}{20{,}800\ hours}\right)(132{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 2.00\ x10^6\ g$

$Solar\ EMERGY = (2.00\ x10^6\ g)(6.7\ x10^9\ \frac{sej}{g})$

$= 1.34 x10^{16} sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 Four Electrician Foremen

Labor Hours = 686.4

Salary = $ 52.90

$Raw\ Units = (4)(\frac{\$52.90}{hour})$ (686.40 hours)

=145,242.24$

$Solar\ EMERGY = (145{,}242.24\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

= 2.90 $x10^{17} se\ j$

S1.2 Four Electricians

Labor Hours = 686.4

Salary = $ 52.40

$Raw\ Units = (4)(\frac{\$\ 52.40}{hour})$ (686.40 hours)

=143,869.44$

$Solar\ EMERGY = (143{,}869.44\$)(2.00\ x10^{12}\frac{sej}{\$})$

=2.88 $x10^{17} se\ j$

S1.3 Two Equipment Operators

Labor Hours = 686.4

Salary = $ 48.80

$Raw\ Units = (2)(\frac{\$\ 48.80}{hour})$ (686.4 hours)

=66,992.64$

$Solar\ EMERGY = (66{,}992.64\$)(2.00\ x10^{12}\frac{sej}{\$})$

=1.34 $x10^{17} se\ j$

S1.4 One Outside Labor Foreman

Labor Hours =686.4

Salary = $ 37.45

$Raw\ Units = (1)(\frac{\$\ 37.45}{hour})$ (686.4 hours)

=25,705.68$

$Solar\ EMERGY = (25{,}705.68\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$5.14\ x10^{16} se\ j$

S1.5 Four Laborers

Labor Hours =686.4

Salary = $ 35.45

$Raw\ Units = (4)(\frac{\$\ 35.45}{hour})$ (686.4 hours)

=97,331.52$

$Solar\ EMERGY = (97{,}331.52\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$1.95\ x10^{17} se\ j$

S1.6 One Cement Finisher

Labor Hours =686.4

Salary = $ 43.05

$Raw\ Units = (\frac{\$\ 43.05}{hour})$ (686.4 hours)

=29,549.52$

$Solar\ EMERGY = (29{,}549.52\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$5.91\ x10^{16} se\ j$

S1.7 Sixteen Electrician Foreman

Labor Hours =693.3

Salary = $ 52.90

$Raw\ Units = (16)(\frac{\$\ 52.90}{hour})$ (693.3 hours)

=586,809.12$

$Solar\ EMERGY = (586{,}809.12\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.17\ x10^{18} se\ j$

S1.8 Sixteen Electricians

Labor Hours =693.3

Salary = $ 52.40

$Raw\ Units = (16)(\frac{\$\ 52.40}{hour})$ (693.3 hours)

=581,262.72$

$Solar\ EMERGY = (581{,}262.72\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.16\ x10^{18} se\ j$

S1.9 Four Equipment Operators

Labor Hours =693.3

Salary = $ 48.80

$Raw\ Units = (4)(\frac{\$\ 48.80}{hour})$ (693.3 hours)

=135,332.16$

$Solar\ EMERGY = (135{,}332.16\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=2.71\ x10^{17} se\ j$

S1.10 Four Common Laborers

Labor Hours =693.3

Salary = $ 35.45

$Raw\ Units = (4)(\frac{\$\ 35.45}{hour})$ (693.3 hours)

=98,309.94$

$Solar\ EMERGY = (98{,}309.94\$)(2.00\ x10^{12} \frac{sej}{\$})$

$=1.97\ x10^{17} se\ j$

S1.11 One Liebherr Mobile Crane Operator

Labor Hours =693.3

Salary = $ 49.00

$Raw\ Units = (\frac{\$\ 49.00}{hour})$ (693.3 hours)

=33,971.70$

$Solar\ EMERGY = (33{,}971.70\$)(2.00\ x10^{12} \frac{sej}{\$})$

$=6.79\ x10^{16} se\ j$

Table HSPR-21: Use Phase - G
Ballast Cleaning at Year 16

Phase-G Use
Environmental Value Engineering EMERGY Analysis Input Table

Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$12.47\ x10^{6}J$		$8.31\ x10^{12}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$12.47\ x10^{6}J$	$6.66\ x10^{5}$	$8.31\ x10^{12}sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$5.98\ x10^{9}J$		$3.95\ x10^{14}sej$
F-1	Equipment	$5.98\ x10^{9}J$	$6.6\ x10^{4}$	$3.95\ x10^{14}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$4.68\ x10^{3}g$		$3.14\ x10^{13}sej$
G-1	Equipment	$4.68\ x10^{3}g$	$6.7\ x10^{9}$	$3.14\ x10^{13}sej$
G-2	Facilities			
G-3	Goods			
G-4	Tools			
S	SERVICES	238.80$		$4.78\ x10^{14}sej$
S-1	Labor	238.80$	$2.00\ x10^{12}$	$4.78\ x10^{14}sej$
S-2	Materials	N/A		

Table HSPR-21: Use Phase - G
Ballast Cleaning at Year 16

Crew

2-Ballast cleaner operators \$ 47.50

1-Outside labor foreman \$ 37.45

3-Laborers \$ 35.45

Equipment

1-Loram HP Shoulder Ballast Cleaner (536,000 pounds)

Duration based on working speed of 2 miles per hour so 1 mile in 30 minutes per track

Environment

E5. Water

E.5.1 Water Transformity = $6.66\ x10^5\ \frac{sej}{J}$

One Water Car with a 667 gal/hour application rate

Duration is 1.0 hour

$$Raw\ Units = (667\ gallons)\left(3.7854\frac{l}{gal}\right)\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)$$

$$= 12.47x10^6 J$$

$$Solar\ EMERGY = (12.47x10^6 J)(6.66x10^5 \frac{sej}{J})$$

$$= \ 8.31x10^{12}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4 \frac{sej}{J}$

F1. Equipment

F1.1 One Shoulder Ballast Cleaner

Fuel consumption = 40 gal/hour

Use = 1 $hour$

$$Raw\ Units = (40\ \frac{gal}{hour})(1\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 5.98\ x10^9 J$

$$Solar\ EMERGY = (5.98\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 3.95x10^{14}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Shoulder Ballast Cleaner

Weight = 536,000 LB

Useful Life = 52,000 hours

Use = 1.0 hour

$$Raw\ Units = (1.0\ hour)\left(\frac{1}{52{,}000\ hours}\right)(536{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 4.68x10^3 g$

$$Solar\ EMERGY = (4.68x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 3.14\ x10^{13} sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 Two Ballast Cleaner Operators

Labor Hours = 1

Salary = $ 47.50

$$Raw\ Units = (2)(\frac{\$\ 47.50}{hour})\ (1\ \text{hour})$$

=95$

$Solar\ EMERGY = (95\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 1.9\ x10^{14} se\ j$

S1.2 One outside labor foreman

Labor Hours = 1

Salary = $ 37.45

$Raw\ Units = (\frac{\$\ 37.45}{hour})\ (1\ hours)$

$=37.45\$$

$Solar\ EMERGY = (37.45\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=7.49\ x10^{13} se\ j$

S1.3 Three laborers

Labor Hours = 1

Salary = $ 35.45

$Raw\ Units = (3)(\frac{\$\ 35.45}{hour})\ (1\ hours)$

$=106.35\$$

$Solar\ EMERGY = (106.35\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$=2.13\ x10^{14} se\ j$

Table HSPR-22: Use Phase - G
Ballast Cleaning at Year 33

	Phase-G Use Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$12.47\ x10^{6}J$	$6.66\ x10^{5}$	$8.31\ x10^{12}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$12.47\ x10^{6}J$		$8.31\ x10^{12}sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$5.98\ x10^{9}J$		$3.95\ x10^{14}sej$
F-1	Equipment	$5.98\ x10^{9}J$	$6.6\ x10^{4}$	$3.95\ x10^{14}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$4.68\ x10^{3}g$		$3.14\ x10^{13}sej$
G-1	Equipment	$4.68\ x10^{3}g$	$6.7\ x10^{9}$	$3.14\ x10^{13}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	238.80$		$4.78\ x10^{14}sej$
S-1	Labor	238.80$	$2.00\ x10^{12}$	$4.78\ x10^{14}sej$
S-2	Materials	N/A		

Table HSPR-22: Use Phase - G
Ballast Cleaning at Year 33

Crew

2-Ballast cleaner operators $ 47.50

1-Outside labor foreman $ 37.45

3-Laborers $ 35.45

Equipment

1-Loram HP Shoulder Ballast Cleaner (536,000 pounds)

Duration based on working speed of 2 miles per hour so 1 mile in 30 minutes per track

Environment

E5. Water

E.5.1 Water Transformity = $7.28\ x10^4\ \frac{sej}{g}$

One Water Car with a 667 gal/hour application rate

Duration is 1.0 hour

$$Raw\ Units = (667\ gallons)\left(3.7854\frac{l}{gal}\right)\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)$$

$$= 12.47x10^6 J$$

$$Solar\ EMERGY = (12.47x10^6 J)(6.66x10^5 \frac{sej}{J})$$

$$= \ 8.31x10^{12}\ sej$$

Fuel Energy

Petroleum Transformity $= 6.6x10^4 \frac{sej}{J}$

F1. Equipment

F1.1 One Shoulder Ballast Cleaner

Fuel consumption = 40 gal/hour

Use = 1 $hour$

$$Raw\ Units = (40\ \frac{gal}{hour})(1\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 5.98\ x10^9 J$$

$$Solar\ EMERGY = (5.98\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= 3.95x10^{14}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1. Equipment

G1.1 One Shoulder Ballast Cleaner

Weight = 536,000 LB

Useful Life = 52,000 hours

Use = 1.0 hour

$$Raw\ Units = (1.0\ hour)\left(\frac{1}{52{,}000\ hours}\right)(536{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 4.68x10^3 g$$

$$Solar\ EMERGY = (4.68x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 3.14\ x10^{13} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 Two Ballast Cleaner Operators

Labor Hours = 1

Salary = $ 47.50

$$Raw\ Units = (2)(\frac{\$\ 47.50}{hour})\ (1\ \text{hour})$$

=95$

$Solar\ EMERGY = (95\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 1.9\ x10^{14} se\ j$

S1.2 One outside labor foreman

Labor Hours = 1

Salary = $ 37.45

$Raw\ Units = (\frac{\$\ 37.45}{hour})$ (1 hours)

=37.45$

$Solar\ EMERGY = (37.45\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=7.49\ x10^{13} se\ j$

S1.3 Three laborers

Labor Hours = 1

Salary = $ 35.45

$Raw\ Units = (3)(\frac{\$\ 35.45}{hour})$ (1 hours)

=106.35$

$Solar\ EMERGY = (106.35\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$=2.13\ x10^{14} se\ j$

Table HPSR-23: Use Phase G
Track Replacement

	Phase-G Use Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$5.03x10^{12}J$		$3.32x10^{17}sej$
F-1	Equipment	$5.03x10^{12}J$	$6.6x10^{4}$	$3.32x10^{17}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$3.36x10^{6}g$		$2.25x10^{16}sej$
G-1	Equipment	$3.36x10^{6}g$	$6.7x10^{9}$	$2.25x10^{16}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	45,727.20$		$9.15x10^{16}sej$
S-1	Labor	45,727.20$	$2.00x10^{12}$	$9.15x10^{16}sej$
S-2	Materials	N/A		

Table HPSR-23: Use Phase G
Track Replacement

Track Replacement (Ballast, Concrete Cross Ties and 140 LB/YD Rail)

Existing track will be demolished and new track installed via the Track Renewal System

Harsco TRT 909

$Rail\ Length = (4)\ (5{,}280\ ft)$

$= 21{,}120/1{,}320\ lf$ Or 16 sections of rail

Rate = $(10{,}560\ lf)(\frac{1\ day}{5{,}280\ lf})$

$= (2\ days)(\frac{8\ hours}{day})$

$= 16\ hours$ To remove and replace rail

Final Ballast= $(1\ ft)(30\ ft)(5280\ ft)\ (\frac{1\ CY}{27\ cf})\ (\frac{2{,}719\ Lbs.}{CY})$

$= 15.95x10^6\ pounds$

Each Herzog car hauls 100,000 pounds so:

$$= (15.95x10^6\ pounds)(\frac{1\ Herzog\ car}{100{,}000\ pounds})$$

$$= 160\ cars$$

So 8 train loads at 20 cars each with a 20 mile round trip at 1 trip per day so:

$= (160\ cars)(\frac{1\ day}{20\ cars})$

= 8 days$(\frac{8\ hours}{day})$

= 64 hours to install ballast

Rail will be delivered on a rail train and staged in 48 hours

Crew

1-Engineer \$ 60.00

1-Assistant Engineer \$ 52.00

4-Labor Foremen $ 37.45

20-Laborers $ 35.45

7-Equipment Operators

2-Welder Foreman $ 52.05

2-Welders $ 50.05

1-Herzog Plus Train Technician $ 47.50

1-Ballast Regulator Operator $ 47.50

1-Tamper Operator - $ 47.50

1-Ballast Under-Cutter Operator $ 47.50

Equipment type

2-Back Hoe Loaders (24,251 pounds)

2-Rail Saws with Clamps (56 pounds)

2-Weld Shearers (100 pounds)

2-Upright Grinders (26 pounds)

2-Hydraulic Power Units (330 pounds)

2-Orgo-Thermit Tool Kits (155 pounds)

12-Orgo-Thermit Single Use Crucibles (77 pounds)

2-Oxygen/Acetylene Tanks (175 Pounds)

2-Work Trucks (8,000 Pounds)

1-Locomotives (250,000 pounds)

20-Herzog GPS Rail Cars (74,000 pounds)

1-Ballast Regulator (56,000 pounds)

1-Tamper (70,000 pounds)

1-Harsco TRT 909 Train ($3.12x10^6\ pounds$)

1-Rail Train ($1.94x10^6\ pounds$)

1-Smart Train ($1.73x10^6$ *pounds*)

1-Harsco Track Under-Cutter (180,000 pounds)

Environment

E5. Water

E.5 No Water Usage

Fuel Energy

Petroleum Transformity = $6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 Two Back Hoe Loaders (24,251Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (2)(3.5\ \frac{gal}{hour})(64\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$=66.99x10^9 J$$

$$Solar\ EMERGY = (66.99\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ 4.42x10^{15}\ sej$$

F1.2 Two Hydraulic Power Units (330 Lbs.)

Fuel consumption = 1.3 gal/hour

$$Raw\ Units = (2)(1.3\ \frac{gal}{hour})(12\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 4.67\ x10^9 J$$

$$Solar\ EMERGY = (4.67x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ 3.08x10^{14}\ sej$$

F1.3 Two Work Trucks (8,000 Lbs.)

Fuel consumption = 4 gal/hour

$$Raw\ Units = (2)(4\ \frac{gal}{hour})(64\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 76.56\ x10^9 J$$

$$Solar\ EMERGY = (76.56x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ 5.05x10^{15}\ sej$$

F1.4 One Smart Train with One Locomotive Engine ($1.73x10^6$ Lbs.)

Fuel consumption = 150 gal/hour

$$Raw\ Units = (150\ \frac{gal}{hour})(64\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$= 1.44\ x10^{12}J$

$$Solar\ EMERGY = (1.44x10^{12}J)(6.6x10^{4}\ \frac{sej}{J})$$

$$= \ 9.50x10^{16}\ sej$$

F1.5 One Rail Train with Two Locomotive Engines ($1.94x10^{6}$ Lbs.)

Fuel consumption = 150 gal/hour

$$Raw\ Units = (2)(150\ \frac{gal}{hour})(48\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$= 2.15\ x10^{12}J$

$$Solar\ EMERGY = (2.15x10^{12}J)(6.6x10^{4}\ \frac{sej}{J})$$

$$= \ 1.42x10^{17}\ sej$$

F1.6 One TRT 909 Train with Three Locomotive Engines ($13.12x10^{6}$ Lbs.)

Fuel consumption = 150 gal/hour

$$Raw\ Units = (3)(150\ \frac{gal}{hour})(16\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$= 1.08\ x10^{12}J$

$$Solar\ EMERGY = (1.08x10^{12}J)(6.6x10^{4}\ \frac{sej}{J})$$

$$= \ 7.13x10^{16}\ sej$$

F1.7 One Ballast Regulator (56,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(64\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$= 76.56\ x10^{9}J$

$$Solar\ EMERGY = (76.56x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$$

$$= \ 5.05x10^{15}\ sej$$

F1.8 One Ballast Tamper (70,000 Lbs.)

Fuel consumption = 10.5 gal/hour

$$Raw\ Units = (10.5\ \frac{gal}{hour})(64\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 100.48\ x10^9 J$$

$$Solar\ EMERGY = (100.48x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 6.63x10^{15}\ sej$$

F1.9 One Track Undercutter (180,000 Lbs.)

Fuel consumption = 40 gal/hour

$$Raw\ Units = (40\ \frac{gal}{hour})(10{,}560\ feet)(\frac{1\ hour}{2{,}050\ feet})\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 30.81\ x10^9 J$$

$$Solar\ EMERGY = (30.81x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 2.03x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Two Back Hoe Loaders

Weight = 24,251 Lbs.

Useful Life = 10,000 hours

Use = 64 hours

$$Raw\ Units = (2)(64\ hours)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 140.80x10^3 g$$

$$Solar\ EMERGY = (140.80x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 9.43\ x10^{14} sej$$

G1.2 Two Hydraulic Rail Saws

Weight = 56 Lbs.

Useful Life = 5,760 hours

Use = 12 hours

$$Raw\ Units = (2)(12\ hours)\left(\frac{1}{5{,}760\ hours}\right)(56\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 105.84\ g$

$$Solar\ EMERGY = (105.84g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 709.13\ x10^{9} sej$$

G1.3 Two Weld Shearers

Weight = 100 Lbs.

Useful Life = 5,760 hours

Use = 12 hours

$$Raw\ Units = (2)(12\ hours)\left(\frac{1}{5{,}760\ hours}\right)(100\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 189g$

$$Solar\ EMERGY = (189g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.27\ x10^{12} sej$$

G1.4 Two Upright Grinders

Weight = 26 Lbs.

Useful Life = 5,760 hours

Use = 12 hours

$$Raw\ Units = (2)(12\ hours)\left(\frac{1}{5{,}760\ hours}\right)(26\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 49.14\ g$

$$Solar\ EMERGY = (49.14\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 329.24x10^{9}sej$$

G1.5 Two Hydraulic Power Units

Weight = 330 Lbs.

Useful Life = 3,840 hours

Use = 12 hours

$$Raw\ Units = (2)(12\ hours)\left(\frac{1}{3{,}840\ hours}\right)(330\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 935.55\ g$$

$$Solar\ EMERGY = (935.55\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 6.27\ x10^{12}sej$$

G1.6 Two Orgo-Thermit Tool Kits

Weight = 155 Lbs.

Useful Life = 1,920 hours

Use = 12 hours

$$Raw\ Units = (2)(12\ hours)\left(\frac{1}{1{,}920\ hours}\right)(155\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 878.85\ g$$

$$Solar\ EMERGY = (878.85\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.89\ x10^{12}sej$$

G1.7 Sixteen Orgo-Thermit Single Use Crucibles

Weight = 77 Lbs.

Useful Life = 0.5 hours

Use = 0.5 hours

$$Raw\ Units = (16)(0.5\ hours)\left(\frac{1}{0.5\ hours}\right)(77\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 558.84\ x10^{3}\ g$$

$$Solar\ EMERGY = (558.84\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 3.74\ x10^{15} sej$$

G1.10 (101) Oxygen/Acetylene Tanks

Weight = 175 Lbs.

Useful Life = 8 hours

Use = 8 hours

$$Raw\ Units = (2)(8\ hours)\left(\frac{1}{8\ hours}\right)(175\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 158.76\ x10^3\ g$$

$$Solar\ EMERGY = (158.76\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.06\ x10^{15} sej$$

G1.9 Two Work Trucks

Weight = 8,000 Lbs.

Useful Life = 5,760 hours

Use = 64 hours

$$Raw\ Units = (2)(64\ hours)\left(\frac{1}{5{,}760\ hours}\right)(8{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 80.64\ x10^3\ g$$

$$Solar\ EMERGY = (80.64x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 5.40\ x10^{14} sej$$

G1.10 One Harsco TRT 909 Train

Weight = $3.12x10^6\ pounds$

Useful Life = 52,000 hours

Use = 16 hours

$$Raw\ Units = (16\ hours)\left(\frac{1}{52{,}000\ hours}\right)(3.12x10^6\ pounds)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 435.46x10^3\ g$

$$Solar\ EMERGY = (435.46\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 2.92\ x10^{15} sej$$

G1.11 One Rail Train

Weight = $1.94x10^6\ pounds$

Useful Life = 52,000 hours

Use = 48 hours

$$Raw\ Units = (48\ hours)\left(\frac{1}{52{,}000\ hours}\right)(1.94x10^6\ pounds)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 812.29x10^3\ g$

$$Solar\ EMERGY = (812.29\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 5.44\ x10^{15} sej$$

G1.12 One Smart Train

Weight = $1.73x10^6\ pounds$

Useful Life = 52,000 hours

Use = 64 hours

$$Raw\ Units = (64\ hours)\left(\frac{1}{52{,}000\ hours}\right)(1.73x10^6\ pounds)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 965.82x10^3\ g$

$$Solar\ EMERGY = (965.82\ x10^3\ g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 6.47\ x10^{15} sej$$

G1.13 One Ballast Regulator

Weight = 56,000 Lbs.

Useful Life = 20,800 hours

Use = 64 hours

$$Raw\ Units = (64\ hours)\left(\frac{1}{20{,}800\ hours}\right)(56{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 78.16x10^{3}\ g$$

$$Solar\ EMERGY = (78.16\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.24\ x10^{14} sej$$

G1.14 One Ballast Tamper

Weight = 70,000 Lbs.

Useful Life = 20,800 hours

Use = 64 hours

$$Raw\ Units = (64\ hours)\left(\frac{1}{20{,}800\ hours}\right)(70{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 97.70x10^{3}\ g$$

$$Solar\ EMERGY = (97.70\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 6.55\ x10^{14} sej$$

G1.15 One Harsco Track Undercutter

Weight = 180,000 Lbs.

Useful Life = 52,000 hours

Use = 16 hours

$$Raw\ Units = (16\ hours)\left(\frac{1}{52{,}000\ hours}\right)(180{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 25.12x10^{3}\ g$$

$$Solar\ EMERGY = (25.12\ x10^{3}\ g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.68\ x10^{14} sej$$

Services

Service/Labor Transformity = $2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 Four Labor Foremen

Labor Hours = 16

Salary = \$ 37.45

$Raw\ Units = (4)(\frac{\$37.45}{hour})$ (16 hours)

=2,396.80\$

$Solar\ EMERGY = (2{,}396.80\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

= 4.79 $x10^{15} se\ j$

S1.2 Twenty Laborers

Labor Hours = 16

Salary = \$ 35.45

$Raw\ Units = (20)(\frac{\$\ 35.45}{hour})$ (16 hours)

=11,344\$

$Solar\ EMERGY = (11{,}344\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

=2.27 $x10^{16} se\ j$

S1.3 Seven Equipment Operators

Labor Hours = 16

Salary = \$ 47.50

$Raw\ Units = (7)(\frac{\$\ 47.50}{hour})$ (16 hours)

=5,320\$

$Solar\ EMERGY = (5{,}320\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.06\ x10^{16} se\ j$

S1.4 Two Welder Forman

Labor Hours =12

Salary = $ 52.05

$Raw\ Units = (2)(\frac{\$\ 52.05}{hour})$ (12 hours)

=1,249.20$

$Solar\ EMERGY = (1{,}249.20\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$2.50\ x10^{15} se\ j$

S1.5 Two Welders

Labor Hours =12

Salary = $ 50.05

$Raw\ Units = (2)(\frac{\$\ 50.05}{hour})$ (12 hours)

=1,201.20$

$Solar\ EMERGY = (1{,}201.20\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$2.40\ x10^{15} se\ j$

S1.6 One Locomotive Engineer

Labor Hours =128

Salary = $ 60.00

$Raw\ Units = (\frac{\$\ 60.00}{hour})$ (128 hours)

=7,680.00$

$Solar\ EMERGY = (7{,}680.00\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$1.54\ x10^{16} se\ j$

S1.7 One Assistant Locomotive Engineer

Labor Hours =128

Salary = $ 52.00

$Raw\ Units = (\frac{\$\ 52.00}{hour})$ (128 hours)

=6,656.00$

$Solar\ EMERGY = (6{,}656.00\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$1.33\ x10^{16} se\ j$

S1.8 One Herzog GPS Rail Car Technician

Labor Hours =64

Salary = $ 47.50

$Raw\ Units = (\frac{\$\ 47.50}{hour})$ (64 hours)

=3,040.00$

$Solar\ EMERGY = (3{,}040.00\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$6.08\ x10^{15} se\ j$

S1.9 One Ballast Regulator Operator

Labor Hours =64

Salary = $ 47.50

$Raw\ Units = (\frac{\$\ 47.50}{hour})$ (64 hours)

=3,040.00$

$Solar\ EMERGY = (3{,}040.00\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$6.08\ x10^{15} se\ j$

S1.10 One Ballast Tamper Operator

Labor Hours =64

Salary = $ 47.50

$Raw\ Units = (\frac{\$\ 47.50}{hour})$ (64 hours)

=3,040.00$

$Solar\ EMERGY = (3{,}040.00\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$6.08\ x10^{15} se\ j$

S1.11 One Ballast Undercutter Operator

Labor Hours =16

Salary = $ 47.50

$Raw\ Units = (\frac{\$\ 47.50}{hour})$ (16 hours)

=760$

$Solar\ EMERGY = (760\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.52\ x10^{15} se\ j$

Table HSPR-24: Demolition Phase H
Demolition

	Phase-H Demolition Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY associated with demolition were not calculated separately given the fact that the Track Renewal System TRT 909 demolished and installed new rail in a simultaneous operation during the use phase.

Table HSPR-24: Demolition Phase H
Demolition

The EMERGY associated with demolition were not calculated separately given the fact that the Track Renewal System TRT 909 demolished and installed new rail in a simultaneous operation during the use phase.

Table HSPR-25 Natural Resource Recycling Phase-I
Natural Resource Recycling

	Phase-I Natural Resource Recycling Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY associated with recycling were not calculated separately given the fact that the Track Renewal System TRT 909 collected the recyclable material in a simultaneous operation during the use phase.

Table HSPR-25 Natural Resource Recycling Phase-I
Natural Resource Recycling

The EMERGY associated with recycling were not calculated separately given the fact that the Track Renewal System TRT 909 collected the recyclable material in a simultaneous operation during the use phase.

Table HSPR-26 Disposal Phase-J
Disposal

	Phase-J Disposal Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY associated with disposal were not calculated separately given the fact that the Track Renewal System TRT 909 collected the disposable material in a simultaneous operation during the use phase.

Table HSPR-26 Disposal Phase-J
Disposal

The EMERGY associated with disposal were not calculated separately given the fact that the Track Renewal System TRT 909 collected the disposable material in a simultaneous operation during the use phase.

Interstate Passenger Car Transportation Alternative 2
Table IH-1: Material Transformity Phases A-C
Top Soil

		Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table		
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$58.68\ x10^9 g$		$1.00\ x10^{20}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	$58.68\ x10^9 g$	$1.71\ x10^9$	$1.00\ x10^{20}\ sej$
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$8.38\ x10^9\ g$	$1.71\ x10^9$	$1.43\ x10^{19}\ sej$
G	GOODS	$8.38\ x10^9\ g$	$1.71\ x10^9$	$1.43\ x10^{19}\ sej$
S	SERVICES	$8.38\ x10^9\ g$	$1.71\ x10^9$	$1.43\ x10^{19}\ sej$

Table IH-1: Material Transformity Phases A-C
Top Soil

Material: Soil with balanced cut and fill

Soil transformity = $1.71\ x10^9$ sej/g

Unit weight of soil ~ 100 $\frac{lbs}{CF}$

Mass (Grading) = $(1\ ft)(350\ ft)(5{,}280\ ft)^1(100\ \frac{LB}{CF})(\frac{453.6\ g}{lb})$

Mass (Grading) = $83.83\ x10^9\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(83.83x10^9 g)$$

$$= 58.68x10^9\ g$$

$$Solar\ EMERGY = (58.68x10^9 g)(1.71x10^9 \frac{sej}{g})$$

$$= 1.00\ x10^{20}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(83.83x10^9 g)$$

$$= 8.38x10^9\ g$$

$$Solar\ EMERGY = (8.38x10^9 g)(1.71x10^9 \frac{sej}{g})$$

$$= 1.43\ x10^{19}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(83.83x10^9 g)$$

$$= 8.38x10^9\ g$$

$$Solar\ EMERGY = (8.38x10^9 g)(1.71x10^9 \frac{sej}{g})$$

$$= 1.43\ x10^{19}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(83.83x10^{9}g)$$

$$= 8.38x10^{9}\ g$$

$$Solar\ EMERGY = (8.38x10^{9}g)(1.71x10^{9}\frac{sej}{g})$$

$$= 1.43\ x10^{19}\ sej$$

Table IH-2 Material Transformity Phases A-C
Lime Stabilized Subgrade

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$297.30\ x10^{6}\ g$	$8.14\ x10^{9}$	$2.42\ x10^{18}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$42.47\ x10^{6}\ g$	$8.14\ x10^{9}$	$3.46\ x10^{17}\ sej$
G	GOODS	$42.47\ x10^{6}\ g$	$8.14\ x10^{9}$	$3.46\ x10^{17}\ sej$
S	SERVICES	$42.47\ x10^{6}\ g$	$8.14\ x10^{9}$	$3.46\ x10^{17}\ sej$

Table IH-2: Material Transformity Phases A-C
Lime Stabilized Subgrade

Material: Hydrated Lime

Hydrated Lime transformity = $8.14\ x10^9$ sej/g

Application Rate = 21 lb/SY

Area $= 76\ ft(5{,}280\ ft)^1 \left(\frac{1SY}{9\ SF}\right)$

$= 44{,}587\ SY$

Mass $= 44{,}587\ SY \left(\frac{21\ lb}{SY}\right)\left(\frac{453.6\ g}{lb}\right)$

$= 424.72\ x10^6\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(424.72x10^6 g)$$

$$= 297.30\ x10^6 g$$

$$Solar\ EMERGY = (297.30x10^6 g)(8.14x10^9 \frac{sej}{g})$$

$$= 2.42\ x10^{18}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(424.72x10^6 g)$$

$$=42.47x10^6 g$$

$$Solar\ EMERGY = (42.47x10^6 g)(8.14x10^9 \frac{sej}{g})$$

$$= 3.46x10^{17}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(424.72x10^6 g)$$

$$=42.47x10^6 g$$

$$Solar\ EMERGY = (42.47x10^6 g)(8.14x10^9 \frac{sej}{g})$$

$$= 3.46x10^{17}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(424.72x10^6 g)$$

$$=42.47x10^6 g$$

$$Solar\ EMERGY = (42.47x10^6 g)(8.14x10^9 \frac{sej}{g})$$

$$= 3.46x10^{17}\ sej$$

Table IH-3 Material Transformity Phases A-C
Subgrade Sealant

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, \$)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$19.11\ x10^{6}\ g$	$1.78\ x10^{9}$	$3.40\ x10^{16}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$2.73\ x10^{6}\ g$	$1.78\ x10^{9}$	$4.86\ x10^{15}\ sej$
G	GOODS	$2.73\ x10^{6}\ g$	$1.78\ x10^{9}$	$4.86\ x10^{15}\ sej$
S	SERVICES	$2.73\ x10^{6}\ g$	$1.78\ x10^{9}$	$4.86\ x10^{15}\ sej$

Table IH-3: Material Transformity Phases A-C
Subgrade Sealant

Material: Asphalt Sealant

Asphalt transformity = $1.78\ x10^9$ sej/g

Application Rate = 0.15 gal/SY

Area $= 76\ ft(5{,}280\ ft)^1 \left(\frac{1SY}{9\ SF}\right)$

$= 44{,}587\ SY$

Mass $= 44{,}587\ SY \left(\frac{0.15\ gal}{SY}\right)\left(\frac{9\ lb}{gal}\right)(\frac{453.6\ g}{lb})$

$= \ 27.30\ x10^6\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(27.30x10^6 g)$$

$$= 19.11\ x10^6 g$$

$$Solar\ EMERGY = (19.11x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 3.40\ x10^{16}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(27.30x10^6 g)$$

$$=2.73x10^6 g$$

$$Solar\ EMERGY = (2.73x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 4.86x10^{15}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(27.30x10^{6}g)$$

$$=2.73x10^{6}g$$

$$Solar\ EMERGY = (2.73x10^{6}g)(1.78x10^{9}\frac{sej}{g})$$

$$= 4.86x10^{15}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(27.30x10^{6}g)$$

$$=2.73x10^{6}g$$

$$Solar\ EMERGY = (2.73x10^{6}g)(1.78x10^{9}\frac{sej}{g})$$

$$= 4.86x10^{15}\ sej$$

Table IH-4 Material Transformity Phases A-C
Prime Coat

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, \$)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$445.96\ x10^{6}\ g$	$1.78\ x10^{9}$	$7.94\ x10^{17}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$63.71\ x10^{6}\ g$	$1.78\ x10^{9}$	$1.13\ x10^{17}\ sej$
G	GOODS	$63.71\ x10^{6}\ g$	$1.78\ x10^{9}$	$1.13\ x10^{17}\ sej$
S	SERVICES	$63.71\ x10^{6}\ g$	$1.78\ x10^{9}$	$1.13\ x10^{17}\ sej$

Table IH-4: Material Transformity Phases A-C
Prime Coat

Material: Asphalt Sealant

Asphalt transformity = $1.78\ x10^{9}$ sej/g

Application Rate = 0.35 gal/SY

Area $= (10)(76\ ft)(5{,}280\ ft)^{1}\left(\frac{1SY}{9\ SF}\right)$

$= 445.87\ x10^{3}\ SY$

Mass $= 445.87\ x10^{3}\ SY\left(\frac{0.35\ gal}{SY}\right)\left(\frac{9\ lb}{gal}\right)(\frac{453.6\ g}{lb})$

$= 637.08\ x10^{6}\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(\ 637.08\ x10^{6}\ g)$$

$$= 445.96\ x10^{6} g$$

$$Solar\ EMERGY = (445.96x10^{6} g)(1.78x10^{9}\frac{sej}{g})$$

$$= 7.94\ x10^{17}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(637.08x10^{6} g)$$

$$=63.71x10^{6} g$$

$$Solar\ EMERGY = (63.71x10^{6} g)(1.78x10^{9}\frac{sej}{g})$$

$$= 1.13x10^{17}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(637.08x10^6 g)$$

$$=63.71x10^6 g$$

$$Solar\ EMERGY = (63.71x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 1.13x10^{17}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(637.08x10^6 g)$$

$$=63.71x10^6 g$$

$$Solar\ EMERGY = (63.71x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 1.13x10^{17}\ sej$$

Table IH-5 Material Transformity Phases A-C
Tack Coat

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$76.45\ x10^{6}\ g$	$1.78\ x10^{9}$	$1.36\ x10^{17}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$10.92\ x10^{6}\ g$	$1.78\ x10^{9}$	$1.94\ x10^{16}\ sej$
G	GOODS	$10.92\ x10^{6}\ g$	$1.78\ x10^{9}$	$1.94\ x10^{16}\ sej$
S	SERVICES	$10.92\ x10^{6}\ g$	$1.78\ x10^{9}$	$1.94\ x10^{16}\ sej$

Table IH-5: Material Transformity Phases A-C
Tack Coat

Material: Asphalt Sealant

Asphalt transformity = $1.78\ x10^9$ sej/g

Application Rate = 0.06 gal/SY

Area $= (10)(76\ ft)(5{,}280\ ft)^1 \left(\frac{1SY}{9\ SF}\right)$

$= 445.87\ x10^3\ SY$

Mass $= 445.87\ x10^3\ SY \left(\frac{0.06\ gal}{SY}\right)\left(\frac{9\ lb}{gal}\right)(\frac{453.6\ g}{lb})$

$= \ 109.21\ x10^6\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(109.21x10^6 g)$$

$$= 76.45\ x10^6 g$$

$$Solar\ EMERGY = (76.45x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 1.36x10^{17}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(109.21x10^6 g)$$

$$=10.92x10^6 g$$

$$Solar\ EMERGY = (10.92x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 1.94x10^{16}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(109.21x10^6 g)$$

$$=10.92x10^6 g$$

$$Solar\ EMERGY = (10.92x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 1.94x10^{16}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(109.21x10^6 g)$$

$$=10.92x10^6 g$$

$$Solar\ EMERGY = (10.92x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 1.94x10^{16}\ sej$$

Table IH-6 Material Transformity Phases A-C
Fog Seal

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$9.39x10^6\ g$	$1.78\ x10^9$	$1.67\ x10^{17}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$1.34\ x10^6\ g$	$1.78\ x10^9$	$2.39\ x10^{15}\ sej$
G	GOODS	$1.34\ x10^6\ g$	$1.78\ x10^9$	$2.39\ x10^{15}\ sej$
S	SERVICES	$1.34\ x10^6\ g$	$1.78\ x10^9$	$2.39\ x10^{15}\ sej$

Table IH-6: Material Transformity Phases A-C
Fog Seal

Material: Asphalt Sealant

Asphalt transformity = $1.78\ x10^9$ sej/g

Application Rate = 0.2 gal/SY

Area $= (28\ ft)(5{,}280\ ft)^1 \left(\frac{1SY}{9\ SF}\right)$

$= 16.43\ x10^3\ SY$

Mass $= 16.43x10^3\ SY \left(\frac{0.2\ gal}{SY}\right)\left(\frac{9\ lb}{gal}\right)\left(\frac{453.6\ g}{lb}\right)$

$= 13.41\ x10^6\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(13.41x10^6 g)$$

$$= 9.39\ x10^6 g$$

$$Solar\ EMERGY = (9.39x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 1.67x10^{17}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(13.41x10^6 g)$$

$$=1.34x10^6 g$$

$$Solar\ EMERGY = (1.34x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 2.39x10^{15}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(13.41x10^6 g)$$

$$=1.34x10^6 g$$

$$Solar\ EMERGY = (1.34x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 2.39x10^{15}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(13.41x10^6 g)$$

$$=1.34x10^6 g$$

$$Solar\ EMERGY = (1.34x10^6 g)(1.78x10^9 \frac{sej}{g})$$

$$= 2.39x10^{15}\ sej$$

Table IH-7 Material Transformity Phases A-C
10 Inch Aggregate Base Course

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$13.17x10^{9}\ g$	$1.00x10^{9}$	$1.32\ x10^{19}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$1.88\ x10^{9}\ g$	$8.5x10^{8}$	$1.60\ x10^{18}\ sej$
G	GOODS	$1.88\ x10^{9}\ g$	$8.5x10^{8}$	$1.60\ x10^{18}\ sej$
S	SERVICES	$1.88\ x10^{9}\ g$	$8.5x10^{8}$	$1.60\ x10^{18}\ sej$

Table IH-7: Material Transformity Phases A-C
10 Inch Aggregate Base Course

Material: Stone Aggregate

Stone (mined) transformity = $1.00\ x10^9$ sej/g

Specific weight compacted = 3180 lb/cy

Volume $= (80\ ft)(5{,}280\ ft)^1(\frac{10}{12}ft)\left(\frac{1CY}{27\ CF}\right)$

$= 13{,}037\ CY$

Mass $= (13{,}037\ CY)\left(\frac{3{,}180\ lb}{CY}\right)(\frac{453.6\ g}{lb})$

$= 18.81\ x10^9\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(18.81x10^9 g)$$

$$= 13.17\ x10^9 g$$

$$Solar\ EMERGY = (13.17x10^9 g)(1.00x10^9 \frac{sej}{g})$$

$$= 1.32\ x10^{19}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(18.81x10^9 g)$$

$$=1.88x10^9 g$$

$$Solar\ EMERGY = (1.88x10^9 g)(8.5x10^8 \frac{sej}{g})$$

$$= 1.60x10^{18}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(18.81x10^9 g)$$

$$=1.88x10^9 g$$

$$Solar\ EMERGY = (1.88x10^9 g)(8.5x10^8 \frac{sej}{g})$$

$$= 1.60x10^{18}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(18.81x10^9 g)$$

$$=1.88x10^9 g$$

$$Solar\ EMERGY = (1.88x10^9 g)(8.5x10^8 \frac{sej}{g})$$

$$= 1.60x10^{18}\ sej$$

Table IH-8 Material Transformity Phases A-C
Asphalt Concrete Pavement

	Phase A-C Material Transformity Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, \$)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$32.03x10^9\ g$	$1.78x10^9$	$5.7\ x10^{19}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
F	FUEL ENERGY (nonrenewable)	$4.58x10^9\ g$	$1.78x10^9$	$8.15\ x10^{18}\ sej$
G	GOODS	$4.58\ x10^9\ g$	$1.78x10^9$	$8.15\ \ x10^{18}\ sej$
S	SERVICES	$4.58\ x10^9\ g$	$1.78x10^9$	$8.15\ \ x10^{18}\ sej$

Table IH-8: Material Transformity Phases A-C
Asphalt Concrete Pavement

Material: Asphalt Concrete

Asphalt Concrete transformity = $1.78\ x10^9$ sej/g

Specific weight compacted = 4,104 lb/CY

Volume (year 0) $= (76\ ft)(5{,}280\ ft)^1(\frac{12.5}{12} ft)\left(\frac{1CY}{27\ CF}\right)$

$= 15{,}481.5\ CY$

Volume (year 12) $= (48\ ft)(5{,}280\ ft)^1(\frac{1.5}{12} ft)\left(\frac{1CY}{27\ CF}\right)$

$= 1{,}173.3\ CY$

Volume (year 23) $= (76\ ft)(5{,}280\ ft)^1(\frac{1.5}{12} ft)\left(\frac{1CY}{27\ CF}\right)$

$= 1{,}857.8\ CY$

Volume (year 34) $= (48\ ft)(5{,}280\ ft)^1(\frac{3}{12} ft)\left(\frac{1CY}{27\ CF}\right)$

$= 2{,}346.7\ CY$

Volume (year 34) $= (76\ ft)(5{,}280\ ft)^1(\frac{3}{12} ft)\left(\frac{1CY}{27\ CF}\right)$

$= 3{,}715.6\ CY$

Mass $= (24{,}574.9\ CY)\left(\frac{4{,}104\ lb}{CY}\right)(\frac{453.6\ g}{lb})$

$= 45.75\ x10^9\ g$

Environment

Transformity due to environment is 70 %

$$Raw\ Units = (0.70)(45.75x10^9 g)$$

$$= 32.03\ x10^9 g$$

$$Solar\ EMERGY = (32.03x10^9 g)(1.78x10^9 \frac{sej}{g})$$

$$= 5.7\ x10^{19}\ sej$$

Fuel Energy

Transformity due to fuel energy is 10 %

$$Raw\ Units = (0.10)(45.75\ x10^9)$$

$$=4.58x10^9 g$$

$$Solar\ EMERGY = (4.58x10^9 g)(1.78x10^9 \frac{sej}{g})$$

$$= 8.15x10^{18}\ sej$$

Goods

Transformity due to goods is 10 %

$$Raw\ Units = (0.10)(45.75\ x10^9)$$

$$=4.58x10^9 g$$

$$Solar\ EMERGY = (4.58x10^9 g)(1.78x10^9 \frac{sej}{g})$$

$$= 8.15x10^{18}\ sej$$

Services

Transformity due to services is 10 %

$$Raw\ Units = (0.10)(45.75\ x10^9)$$

$$=4.58x10^9 g$$

$$Solar\ EMERGY = (4.58x10^9 g)(1.78x10^9 \frac{sej}{g})$$

$$= 8.15x10^{18}\ sej$$

Table IH-9: Design Phase D
Design

	Phase-D Design (Architectural and Engineering) Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY associated with design were not calculated separately based upon the assumption that the design for high-speed passenger rail and interstate passenger car transportation are both of above average complexity and as such assumed equivalent for this analysis.

APPENDIX C: EMERGY INPUT TABLES

Table IH-10: Component Production Phase E
Phase-E: EMERGY Input

	Phase-E Component Production Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY inputs were zero because no components were produced for the Interstate Highway Option.

Table IH-10: Component Production Phase E
Component Production

The EMERGY inputs were zero because no components were produced for the Interstate Highway Option.

Table IH-11: Construction Phase F
Clearing and Grubbing

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$2.33\ x10^{12}\ J$		$1.54\ x10^{17}\ sej$
F-1	Equipment	$2.33\ x10^{12}\ J$	$6.6\ x10^{4}$	$1.54\ x10^{17}\ sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.36\ x10^{6} g$		$1.58\ x10^{16} sej$
G-1	Equipment	$2.36\ x10^{6} g$	$6.7\ x10^{9}$	$1.58\ x10^{16} sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	145,583.73$		$2.91\ x10^{17} sej$
S-1	Labor	145,583.73$	$2.0\ x10^{12}$	$2.91\ x10^{17} sej$
S-2	Materials	N/A		

Table IH-11: Construction Phase F
Clearing and Grubbing

$$Area = (350\ ft)(5{,}280\ ft)$$

$$= 1.85\ x10^6 sf\,(\frac{1\ Acre}{43{,}560\ sf})$$

$$= 42.47\ Acres$$

$$Duration = (42.47\ Acres)(\frac{1\ day}{0.7\ Acres})$$

$$= 60.67\ days\ (8\ \frac{hours}{day})$$

$$= 485.36\ hours$$

Crew type is B-7 Modified

1-Labor foreman$ 37.45 per hour

4-Laborer $ 35.45 per hour

1-Equipment Operator $ 47.50

2-Truck Drivers $ 36.60

Equipment type

2-Dump Trucks (25,000 pounds)

1-Brush Chipper 130 HP (6,907 pounds)

1-Track Loader 3 CY (44,577 pounds)

2-Chain Saws 36 Inch Bar (23 pounds)

Environment

E5. No Water Usage

Fuel Energy

Petroleum Transformity $= 6.6x10^4\ \frac{sej}{J}$

F1. Equipment

F1.1Two Dump Trucks 25,000 lbs.
Fuel consumption = 8 gal/hour

$$Raw\ Units = (2)(8\ \frac{gal}{hour})(485.36\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 1.16\ x10^{12}J$

$$Solar\ EMERGY = (1.16x10^{12}J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 7.66x10^{16}\ sej$

F1.2 One Bruch Chipper 130 HP

Fuel consumption = 7 gal/hour

Use = 485.36 hours

$$Raw\ Units = (7\ \frac{gal}{hour})(485.36\ hours)(\frac{barrel}{42\ gal})(6.28x10^9\ \frac{J}{barrel})^1$$

$= 508.01x10^9J$

$$Solar\ EMERGY = (508.01x10^9J)(6.6x10^4\ \frac{sej}{J})$$

$= 3.35\ x10^{16}sej$

F1.3 One Track Loader 3 CY

Fuel consumption = 7.7 gal/hour

Use = 485.36 hours

$$Raw\ Units = (7.7\ \frac{gal}{hour})(485.36\ hours)(\frac{barrel}{42\ gal})(6.28x10^9\ \frac{J}{barrel})^1$$

$= 558.81x10^9J$

$$Solar\ EMERGY = (558.81x10^9J)(6.6x10^4\ \frac{sej}{J})$$

$= 3.69\ x10^{16}sej$

F1.4 Two Chain Saws 36 inch

Fuel consumption = 0.7 gal/hour

Use = 485.36 hours

$$Raw\ Units = (2)(0.7\ \frac{gal}{hour})(485.36\ hours)(\frac{barrel}{42\ gal})(6.28x10^9\ \frac{J}{barrel})^1$$

$= 101.60x10^9J$

$$Solar\ EMERGY = (101.60x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= 6.71x10^{15} sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Two Dump Trucks

Weight = 25,000 LB Each

Useful Life = 10,000 hours

Use = 485.36 hours

$$Raw\ Units = 2(485.36\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 1.10x10^6 g$$

$$Solar\ EMERGY = (1.10x10^6 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 7.37\ x10^{15} sej$$

G1.2 One Brush Chipper (130 HP)

Weight = 6,907 LB

Useful Life = 6,000 hours

Use = 485.36 hours

$$Raw\ Units = (485.36\ hours)\left(\frac{1}{6{,}000\ hours}\right)(6{,}907\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 253.44x10^3 g$$

$$Solar\ EMERGY = (253.44x10^3 g)(6.7\ x10^9\ sej/g)$$

$$= 1.70\ x10^{15} sej$$

G1.3 One Track Loader 3 CY

Weight = 44,577 LB

Useful Life = 10,000 hours

Use = 485.36 hours

$$Raw\ Units = (485.36\ hours)\left(\frac{1}{10{,}000\ hours}\right)(44{,}577\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 981.40x10^{3}g$

$$Solar\ EMERGY = (981.40x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 6.58\ x10^{15} se\ j$$

G1.4 Two Chain Saws 36 Inch

Weight = 23 LB

Useful Life = 400 hours

Use = 485.36 hours

$$Raw\ Units = (2)(485.36\ hours)\left(\frac{1}{400\ hours}\right)(23\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$=25.32x10^{3}g$

$$Solar\ EMERGY = (25.32x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.7\ x10^{14} se\ j$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 485.36
Salary = $ 37.45

$$Raw\ Units = (\frac{\$\ 37.45}{hour})\ (485.36\ \text{hours})$$

=18,176.73$

$$Solar\ EMERGY = (18{,}176.73\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$$= 3.64\ x10^{16} se\ j$$

S1.2 Four Laborers

Labor Hours = 485.36

Salary = $ 35.45

$$Raw\ Units = 4(\frac{\$\ 35.45}{hour})\ (485.36\ \text{hours})$$

$$=68{,}824.05\$$$

$$Solar\ EMERGY = (68{,}824.05\$)(2.00\ x10^{12}\ \frac{sej}{\$})$$

$$=1.38\ x10^{17} se\ j$$

S1.3 One Equipment Operator

Labor Hours = 485.36

Salary = $ 47.50

$$Raw\ Units = (\frac{\$\ 47.50}{hour})\ (485.36\ \text{hours})$$

$$=23{,}054.60\$$$

$$Solar\ EMERGY = (\ 23{,}054.60\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$$= 4.61\ x10^{16} se\ j$$

S1.4 Two Truck Drivers

Labor Hours = 485.36

Salary = $ 36.60

$$Raw\ Units = (2)(\frac{\$\ 36.60}{hour})\ (485.36\ \text{hours})$$

$$=35{,}528.35\$$$

$$Solar\ EMERGY = (35{,}528.35\$)(2.00\ x10^{12}\frac{sej}{\$})$$

$$= 7.11\ x10^{16} se\ j$$

Table IH-12 Construction Phase F
Top Soil Stripping and Stockpiling

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	$3.19x10^{11}J$		$2.11\ x10^{16}sej$
F-1	Equipment	$3.19\ x10^{11}J$	$6.6\ x10^{4}$	$2.11\ x10^{16}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$4.03x10^{5}g$		$2.70\ x10^{15}sej$
G-1	Equipment	$4.03\ x10^{5}g$	$6.7\ x10^{9}$	$2.70\ x10^{15}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	11,897$		$2.38\ x10^{16}$ sej
S-1	Labor	11,897$	$2.00\ x10^{12}$	$2.38\ x10^{16}$ sej
S-2	Materials	N/A		

Table IH-12: Construction Phase F
Top Soil Stripping and Stockpiling

$$Volume = (1ft)(350\ ft)(5{,}280\ ft)(\frac{1CY}{27\ CF})$$

$$= 68.4x10^3\ CY$$

$$Duration = (68.4x10^3\ CY)(\frac{1\ day}{3{,}000\ CY})$$

$$= 22.8\ days\ (\ 8\frac{hours}{day})$$

$$= 182.4\ hours$$

Crew type is B-10M

1-Equipment Operator $ 47.50

0.5-Laborer $ 35.45 per hour

Equipment type

1-Dozer 300 HP

Environment

E5. No Water Usage

Fuel Energy

Petroleum Transformity = $6.6x10^4\,\frac{sej}{J}$

F1. Equipment

F1.1 One Dozer (87,733 Lbs.)

Fuel consumption = 11.7 gal/hour

$$Raw\ Units = (11.7\ \frac{gal}{hour})(182.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\,\frac{J}{barrel}\right)^1$$

$$= 319.1\ x10^9 J$$

$$Solar\ EMERGY = (319.1\ x10^9 J)(6.6x10^4\,\frac{sej}{J})$$

$$=\ \ 2.11x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Dozer 300 HP

Weight = 87,733 Lbs.

Useful Life = 18,000 hours

Use = 182.4 hours

$$Raw\ Units = (182.4\ hours)\left(\frac{1}{18{,}000\ hours}\right)(87{,}733\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 403.26x10^3 g$$

$$Solar\ EMERGY = (403.26x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 2.7\ x10^{15} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 182.4

Salary = $ 47.50

$$Raw\ Units = (\frac{\$\ 47.50}{hour})\ (182.4\ \text{hours})$$

=8,664$

$$Solar\ EMERGY = (8{,}664\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

$$= 1.73\ x10^{16} se\ j$$

S1.2 Laborer-1/2

Labor Hours = 182.4

Salary = $ 35.45

$Raw\ Units = (1/2)(\frac{\$\ 35.45}{hour})$ (182.4 hours)

=3,233$

$Solar\ EMERGY = (3{,}233\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=6.47\ x10^{15} se\ j$

Table IH-13: Construction Phase F
Rough Grading

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT		N/A	
E-1	Atmosphere		N/A	
E-2	Ecol. Prod.		N/A	
E-3	Energy		N/A	
E-4	Land		N/A	
E-5	Water		N/A	
E-6	Materials		N/A	
F	FUEL ENERGY	$3.71x10^{11}J$		$2.45x10^{16}sej$
F-1	Equipment	$3.71x10^{11}J$	$6.6x10^{4}$	$2.45x10^{16}sej$
F-2	Facilities		N/A	
F-3	Materials		N/A	
G	GOODS	$5.98x10^{5}g$		$4.01x10^{15}sej$
G-1	Equipment	$5.98x10^{5}g$	$6.7x10^{9}$	$4.01x10^{15}sej$
G-2	Facilities			
G-3	Goods			
G-4	Tools			
S	SERVICES	41,143.20$		$8.23x10^{16}sej$
S-1	Labor	41,143.20$	$2.00x10^{12}$	$8.23x10^{16}sej$
S-2	Materials			

Table IH-13: Construction Phase F
Rough Grading

$Area = (350\ ft)(5{,}280\ ft)$

$= (1.85\ x10^6 sf\ )$

$Duration = (1.85\ x10^6 sf)(\frac{1\ day}{60{,}000\ sf})$

$= 31\ days\ (8\ \frac{hours}{day})$

$= 248\ hours$

Crew type is Two B-11L

2-Equipment Operator \$ 47.50 per hour

2-Laborer \$ 35.45 per hour

Equipment type

2-Grader (39,892 pounds)

Environment

E5. No Water Usage

Fuel Energy

Petroleum Transformity = $6.6x10^4\ \frac{sej}{J}$

F1. Equipment

F1.1 Two Graders (39,982 Lbs.)

Fuel consumption = 5.0 gal/hour

$Raw\ Units = (2)(5.0\ \frac{gal}{hour})(248\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$

$= 370.82\ x10^9 J$

$Solar\ EMERGY = (370.82\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$

$= \ 2.45x10^{16}\ sej$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Two Graders

Weight = 39,982 Lbs.

Useful Life = 15,000 hours

Use = 248 hours

$$Raw\ Units = (2)(248\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}892LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 598.34x10^{3}g$

$$Solar\ EMERGY = (598.34x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 4.01\ x10^{15}sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 Two Equipment Operators

Labor Hours = 248

Salary = \$ 47.50

$$Raw\ Units = (2)(\frac{\$\ 47.50}{hour})\ (248\ \text{hours})$$

=23,560\$

$$Solar\ EMERGY = (23{,}560.00\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

$= 4.71\ x10^{16}se\ j$

S1.2 Two Laborers

Labor Hours = 248

Salary = \$ 35.45

$Raw\ Units = (2)(\frac{\$\,35.45}{hour})$ (248 hours)

=17,583.20$

$Solar\ EMERGY = (17{,}583.20\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=3.52\ x10^{16} se\ j$

Table IH-14: Construction Phase F
Fine Grading

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$4.82x10^{8}J$		$3.21x10^{14}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$4.82x10^{8}J$	$6.66x10^{5}$	$3.21x10^{14}sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$4.41x10^{11}J$		$2.91x10^{16}sej$
F-1	Equipment	$4.41x10^{11}J$	$6.60x10^{4}$	$2.91x10^{16}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$641.99x10^{3}g$		$4.30x10^{15}sej$
G-1	Equipment	$641.99x10^{3}g$	$6.70x10^{9}$	$4.30x10^{15}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	37,023.56$		$7.40x10^{16}sej$
S-1	Labor	37,023.56$	$2.00x10^{12}$	$7.40x10^{16}sej$
S-2	Materials	N/A		

Table IH-14: Construction Phase F
Fine Grading

Crew type is B-32C for fine grading

1-Labor Foreman $ 37.45

2-Laborer $ 35.45 per hour

3-Equipment Operator $ 47.50 per hour

1-Truck Driver $ 36.60

Equipment type

1-Grader (39,892 pounds)

1-Tandem Roller (23,525 pounds)

1-Dozer (48,588 Pounds)

1-Water Truck (25,000 pounds)

$$Duration = (96\ ft)(5{,}280\ ft)(\frac{1\ sy}{9\ sf})$$

$$= 56.32\ x10^3\ \ sy\ (\frac{1 day}{3{,}500\ sy})$$

$$= 16.1\ days(\frac{8\ hours}{day})$$

$$= 128.8\ hours$$

Environment

E5. Water

1,600 gal/day per roller

Volume= $(16.1\ days)(1{,}600\ \frac{gal}{day})$

$$= 25{,}760\ gallons$$

$$Raw\ Units = (25{,}760\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^1$$

$$= 481.71\ x10^6 J$$

$$Solar\ EMERGY = (481.71\ x10^6 J)(6.66x10^5 \frac{sej}{J})$$

$$= \ 3.21x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Grader (39,892 Lbs.)

Fuel consumption = 5.0 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(128.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 96.29\ x10^9 J$$

$$Solar\ EMERGY = (96.29\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 6.36x10^{15}\ sej$$

F1.2 One Tandem Roller (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = \ (2.5\ \frac{gal}{hour})(128.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 48.15\ x10^9 J$$

$$Solar\ EMERGY = (48.15\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 3.18x10^{15}\ sej$$

F1.3 One Dozer (48,588 Lbs.)

Fuel consumption = 7.4 gal/hour

$$Raw\ Units = (7.4\ \frac{gal}{hour})(128.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 142.51\ x10^9 J$$

$$Solar\ EMERGY = (142.51\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 9.41x10^{15}\ sej$$

F1.4 One Water Truck (25,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(128.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 154.07\ x10^9 J$$

$$Solar\ EMERGY = (154.07\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 1.02x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Grader

Weight = 39,982 Lbs.

Useful Life = 15,000 hours

Use = 128.8 hours

$$Raw\ Units = (128.8\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}982\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 155.73x10^3 g$$

$$Solar\ EMERGY = (155.73x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.04\ x10^{15} sej$$

G1.2 One Tandem Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 128.8 hours

$$Raw\ Units = (128.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 137.44x10^3 g$$

$$Solar\ EMERGY = (137.44x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 9.21\ x10^{14} sej$$

G1.3 One Dozer

Weight = 48,588 Lbs.

Useful Life = 14,000 hours

Use = 128.8 hours

$$Raw\ Units = (128.8\ hours)\left(\frac{1}{14{,}000\ hours}\right)(48{,}588\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 202.76x10^3 g$$

$$Solar\ EMERGY = (202.76x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.36x10^{15} sej$$

G1.4 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 128.8 hours

$$Raw\ Units = (128.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 146.06x10^3 g$$

$$Solar\ EMERGY = (146.06x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 9.79\ x10^{14} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12} \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 128.8

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (128.8 hours)

=4,823.56$

$Solar\ EMERGY = (4{,}823.56\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 9.65\ x10^{15} se\ j$

S1.2 Two Laborers

Labor Hours = 128.8

Salary = $ 35.45

$Raw\ Units = \ (2)(\frac{\$\ 35.45}{hour})$ (128.8 hours)

=9,131.92$

$Solar\ EMERGY = (9{,}131.92\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=1.83\ x10^{16} se\ j$

S1.3 Three Equipment Operators

Labor Hours = 128.8

Salary = $ 47.50

$Raw\ Units = (3)(\frac{\$\ 47.50}{hour})$ (128.8 hours)

=18,354$

$Solar\ EMERGY = (18{,}354\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=3.67\ x10^{16} se\ j$

S1.6 One Truck Driver

Labor Hours = 128.8

Salary = $ 36.60

$Raw\ Units = \left(\frac{\$\ 36.60}{hour}\right)$ (128.8 hours)

=4,714.08$

$Solar\ EMERGY = (4{,}714.08\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=9.43 $x10^{15} se\ j$

Table IH-15: Construction Phase F
Lime Soil Stabilization

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$8.89x10^8 J$		$5.92x10^{14} sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$8.89\ x10^8 J$	$6.66x10^5$	$5.92x10^{14} sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$2.44x10^{12} J$		$1.61x10^{17} sej$
F-1	Equipment	$2.44x10^{12} J$	$6.60x10^4$	$1.61x10^{17} sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.36x10^6 g$		$1.58x10^{16} sej$
G-1	Equipment	$2.36x10^6 g$	$6.70x10^9$	$1.58x10^{16} sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	86,181.68$		$1.72x10^{17} sej$
S-1	Labor	86,181.68$	$2.00x10^{12}$	$1.72x10^{17} sej$
S-2	Materials	N/A		

Table IH-15: Construction Phase F
Lime Soil Stabilization

Crew type is B-74 for lime soil stabilization

1-Labor foreman $ 37.45

1-Laborer $ 35.45

4-Equipment Operators $ 47.50

2-Truck Driver $ 36.60

Equipment Type

1-Grader (39,892 pounds)

2-Road Reclaimers (62,060 pounds)

1-Flatbed 3 Ton Work Truck (8,000 pounds)

1-Semi Tractor Truck with Tanker Spreader (35,000 pounds)

1-Water Truck 5,000 gallons/day capacity (25,000 pounds)

1-Vibratory Roller (41,214 pounds)

Duration:

$$= (86ft)(5{,}280\ ft)(\frac{SY}{9\ sf})$$

$$= 50{,}453.3\ SY(\frac{1\ day}{1{,}700\ SY})$$

$$= 29.7\ days(\frac{8\ hours}{day})$$

$$= 237.6\ hours$$

Environment

Environment

E5. Water

1,600 gal/day per roller

Volume= $(29.7\ days)(1{,}600\ \frac{gal}{day})$

$$= 47{,}520\ gallons$$

$$Raw\ Units = (47{,}520\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$$

$$= 888.62\ x10^{6}J$$

$$Solar\ EMERGY = (888.62\ x10^{6}J)(6.66x10^{5}\ \frac{sej}{J})$$

$$= 5.92x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^{4}\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Grader (39,892 Lbs.)

Fuel consumption = 5.0 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(237.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$$= 177.63\ x10^{9}J$$

$$Solar\ EMERGY = (177.63\ x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$$

$$= 1.17x10^{16}\ sej$$

F1.2 Two Road Reclaimers (62,060 Lbs.)

Fuel consumption = 18 gal/hour

$$Raw\ Units = (2)(18\ \frac{gal}{hour})(237.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$$= 1.28\ x10^{12}J$$

$$Solar\ EMERGY = (1.28\ x10^{12}J)(6.6x10^4\frac{sej}{J})$$

$$= \ 8.45x10^{16}\ sej$$

F1.3 One Flatbed 3 Ton Work Truck (8,000 Lbs.)

Fuel consumption = 4 gal/hour

$$Raw\ Units = \ (4\ \frac{gal}{hour})(237.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$= 142.11\ x10^9J$$

$$Solar\ EMERGY = (142.11\ x10^9J)(6.6x10^4\frac{sej}{J})$$

$$= \ 9.38x10^{15}\ sej$$

F1.4 One Semi Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(237.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$= 284.21\ x10^9J$$

$$Solar\ EMERGY = (284.21\ x10^9J)(6.6x10^4\frac{sej}{J})$$

$$= \ 1.88x10^{16}\ sej$$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = \ (8\ \frac{gal}{hour})(237.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$= 284.21\ x10^9J$$

$$Solar\ EMERGY = (284.21\ x10^9J)(6.6x10^4\frac{sej}{J})$$

$$= \ 1.88x10^{16}\ sej$$

F1.6 One Vibratory Roller (41,214 Lbs.)

Fuel consumption = 5 gal/hour

$$Raw\ Units = (5\ \frac{gal}{hour})(237.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$= 177.63\ x10^9 J$

$$Solar\ EMERGY = (177.63\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= 1.17x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Grader

Weight = 39,982 Lbs.

Useful Life = 15,000 hours

Use = 237.6 hours

$$Raw\ Units = (237.6\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}982\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 287.27x10^3 g$

$$Solar\ EMERGY = (287.27x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.92\ x10^{15} sej$$

G1.2 Two Road Reclaimers

Weight = 62,060 Lbs.

Useful Life = 18,000 hours

Use = 237.6 hours

$$Raw\ Units = (2)(237.6\ hours)\left(\frac{1}{18{,}000\ hours}\right)(62{,}060\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 743.17x10^3 g$

$$Solar\ EMERGY = (743.17x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 4.98\ x10^{15} sej$$

G1.3 One Flatbed 3 Ton Work truck

Weight = 8,000 Lbs.

Useful Life = 7,500 hours

Use = 237.6 hours

$$Raw\ Units = (237.6\ hours)\left(\frac{1}{7{,}500\ hours}\right)(8{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 114.96x10^3 g$

$$Solar\ EMERGY = (114.96x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 7.70\ x10^{14} sej$

G1.3 One Semi Tractor Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 237.6 hours

$$Raw\ Units = (237.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 377.21x10^3 g$

$$Solar\ EMERGY = (377.21x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 2.53x10^{15} sej$

G1.4 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 237.6hours

$$Raw\ Units = (237.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 269.44x10^3 g$

$$Solar\ EMERGY = (269.44x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.81\ x10^{15} sej$$

G1.5 One Vibratory Roller

Weight = 41,214 Lbs.

Useful Life = 10,000 hours

Use = 237.6 hours

$$Raw\ Units = (237.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(41{,}214\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 444.19x10^3 g$

$$Solar\ EMERGY = (444.19x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 2.98x10^{15} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 237.6

Salary = \$ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (237.6 hours)

=8,898.12\$

$Solar\ EMERGY =$ (8,898.12\$) $(2.00\ x10^{12}\ \frac{sej}{\$})$

= 1.78 $x10^{16} se\ j$

S1.2 One Laborer

Labor Hours = 237.6

Salary = $ 35.45

$Raw\ Units =\ (\frac{\$\ 35.45}{hour})$ (237.6 hours)

=8,422.92$

$Solar\ EMERGY\ = (8{,}422.92\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=1.68\ x10^{16} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 237.6

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$\ 47.50}{hour})$ (237.6 hours)

=45,144$

$Solar\ EMERGY\ = (45{,}144\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=9.03\ x10^{16} se\ j$

S1.6 Two Truck Drivers

Labor Hours = 237.6

Salary = $ 36.60

$Raw\ Units = (2)(\frac{\$\ 36.60}{hour})$ (237.6 hours)

=17,392.32$

$Solar\ EMERGY\ = (17{,}392.32\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=3.48\ x10^{16} se\ j$

Subgrade Sealant

Crew type is B-45

1-Equipment Operator \$ 47.50

1-Truck Driver \$ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (80\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 46{,}933.3\ SY$$

$$Mass = (46{,}933.3\ SY)(0.15\frac{gallon}{SY})$$

$$= 7{,}040\ gallons$$

$$\text{Rate} \quad = (46{,}933.3\ SY)(\frac{1\ day}{5{,}000\ SY})$$

$$= 9.4\ days\left(8\frac{hrs}{day}\right)$$

$$= 75.2\ hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

$$\text{Petroleum Transformity} = 6.6x10^4\frac{sej}{J}$$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(75.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$=89.95x10^9 J$

$$Solar\ EMERGY = (89.95\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 5.94x10^{15}\ sej$$

Goods
Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$
G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 75.2 hours

$$Raw\ Units = (75.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 119.39x10^3 g$

$$Solar\ EMERGY = (119.39x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 8.00x10^{14}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12} \frac{sej}{\$}$
S1.1 One Equipment Operator

Labor Hours = 75.2

Salary = \$ 47.50

$$Raw\ Units = (\frac{\$47.50}{hour})\ (75.2hours)$$

=3,572\$

$$Solar\ EMERGY = (3{,}572\$)\ (2.00\ x10^{12} \frac{sej}{\$})$$

$= 7.14\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 75.2

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (75.2 hours)

=2,752.32$

$Solar\ EMERGY = (2{,}752.32\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=5.50\ x10^{15} se\ j$

Table IH-16: Construction Phase F
10 Inch Aggregate Base Course

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$1.22x10^9 J$		$8.13x10^{14} sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$1.22x10^9 J$	$6.66x10^5$	$8.13x10^{14} sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$3.78x10^{12} J$		$2.50x10^{17} sej$
F-1	Equipment	$3.78x10^{12} J$	$6.6x10^4$	$2.50x10^{17} sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$3.95x10^6 g$		$2.64x10^{16} sej$
G-1	Equipment	$3.95\ x10^6 g$	$6.7x10^9$	$2.64x10^{16} sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	136,319.12$	$2.00x10^{12}$	$2.73x10^{17} sej$
S-1	Labor	N/A		
S-2	Materials	N/A		

Table IH-16: Construction Phase F
10 Inch Aggregate Base Course

Material: Aggregate

Stone (mined) transformity = $1.00\ x10^9$ sej/g

Stone specific weight (compacted) = 3,180 lb/CY

Specific weight compacted = 3180 lb/cy

Volume $= (80\ ft)(5{,}280\ ft)^1(\frac{10}{12}ft)\left(\frac{1CY}{27\ CF}\right)$

$= 13{,}037\ CY$

Mass $= (13{,}037\ CY)\left(\frac{3{,}180\ lb}{CY}\right)(\frac{1\ Ton}{2{,}000\ lb})$

$= 20.73\ x10^3\ tons$

Compaction Rate $= \frac{1{,}000\ CY}{Day}$

Duration $= 13{,}037\ CY(\frac{1\ day}{1{,}000\ CY})$

$= 13\ days(\frac{8\ hours}{Day})$

$= 104\ hours$

Hauling Duration $= 20.73\ x10^3\ tons(\frac{1\ trip}{16\ tons})$

$= say\ 1{,}296\ truck\ round\ trips$

$= \frac{1{,}296\ trips}{13\ days}$

$= \frac{100\ trips}{day}$

Each round trip is ~ 20 miles and takes ~ 2 hours. Therefore a truck can make 4 trips a day, so use 25 trucks.

Crew type is B-36B Modified

1-Labor Foreman $ 37.45

2-Laborers $ 35.45 per hour

26-Truck Drivers $ 36.60 per hour

4-Equipment Operator $ 47.50 per hour

Equipment type

1-Grader (39,892 pounds)

1-Front End Track Loader (44,577 pounds)

1-Dozer (87,733 pounds)

1-Roller (41,214 pounds)

1-Water Truck (25,000 pounds)

25-Dump Trucks (25,000 pounds)

Environment

E5. Water

E.5.1: (1) Water Truck 5,000 $\frac{gal}{day}$

Volume= $(13\ days)(5{,}000\ \frac{gal}{day})$

$= 65{,}000\ gallons$

$Raw\ Units = (65{,}000\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$

$= 1.22\ x10^{9}J$

$Solar\ EMERGY = (1.22\ x10^{9}J)(6.66x10^{5}\ \frac{sej}{J})$

$= \ 8.13x10^{14}\ sej$

Fuel Energy

Petroleum Transformity = $6.6x10^{4}\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Grader (39,892 Lbs.)

Fuel consumption = 5.0 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(104\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 77.75\ x10^9 J$$

$$Solar\ EMERGY = (77.75\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 5.13x10^{15}\ sej$$

F1.2 One Front End Track Loader (44,577 Lbs.)

Fuel consumption = 7.7 gal/hour

$$Raw\ Units = (7.7\ \frac{gal}{hour})(104\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 119.74\ x10^9 J$$

$$Solar\ EMERGY = (119.74\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 7.90x10^{15}\ sej$$

F1.3 One Dozer (87,733 Lbs.)

Fuel consumption = 11.7 gal/hour

$$Raw\ Units = (11.7\ \frac{gal}{hour})(104\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 181.94\ x10^9 J$$

$$Solar\ EMERGY = (181.94x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 1.2x10^{16}\ sej$$

F1.4 One Roller (42,214 Lbs.)

Fuel consumption = 5 gal/hour

$$Raw\ Units = (5.0\ \frac{gal}{hour})(104\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 77.75\ x10^9 J$$

$$Solar\ EMERGY = (77.75\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 5.13x10^{15}\ sej$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$Raw\ Units = (8\ \frac{gal}{hour})(104\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$

$= 124.40\ x10^{9}J$

$Solar\ EMERGY = (124.40\ x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$

$= \ 8.21x10^{15}\ sej$

F1.6 Twenty Five Dump Trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$Raw\ Units = (25)(8\ \frac{gal}{hour})(104\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$

$= 3.11\ x10^{12}J$

$Solar\ EMERGY = (3.11\ x10^{12}J)(6.6x10^{4}\ \frac{sej}{J})$

$= \ 2.05x10^{17}\ sej$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 One Grader

Weight = 39,982 Lbs.

Useful Life = 15,000 hours

Use = 104 hours

$Raw\ Units = (104\ hours)\left(\frac{1}{15{,}000\ hours}\right)(39{,}982\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 125.74x10^{3}g$

$Solar\ EMERGY = (125.74x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 8.42\ x10^{14} sej$

G1.2 One Front-end Track Loader

Weight = 44,577 Lbs.

Useful Life = 10,000 hours

Use = 104 hours

$$Raw\ Units = (104\ hours)\left(\frac{1}{10{,}000\ hours}\right)(44{,}577\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 210.29x10^{3} g$

$$Solar\ EMERGY = (210.29x10^{3} g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 1.41\ x10^{15} sej$

G1.3 One Dozer

Weight = 87,733 Lbs.

Useful Life = 18,000 hours

Use = 104 hours

$$Raw\ Units = (104\ hours)\left(\frac{1}{18{,}000\ hours}\right)(87{,}733\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 229.93x10^{3} g$

$$Solar\ EMERGY = (229.93x10^{3} g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 1.54\ x10^{15} sej$

G1.4 One Roller

Weight = 41,214 Lbs.

Useful Life = 10,000 hours

Use = 104 hours

$$Raw\ Units = (104\ hours)\left(\frac{1}{10{,}000\ hours}\right)(41{,}214\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 194.42x10^{3} g$

$Solar\ EMERGY = (194.42x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 1.30\ x10^{15} sej$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 104 hours

$Raw\ Units = (104\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 117.94x10^3 g$

$Solar\ EMERGY = (117.94x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 7.90x10^{14} sej$

G1.6 Twenty Five Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 104 hours

$Raw\ Units = (25)(104\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 2.95x10^6 g$

$Solar\ EMERGY = (2.95x10^6 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 1.98x10^{16} sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 104

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (104 hours)

=3,894.80$

$Solar\ EMERGY = (3{,}894.80\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

= 7.79 $x10^{15} se\ j$

S1.2 Two Laborers

Labor Hours = 104

Salary = $ 35.45

$Raw\ Units = (2)(\frac{\$\ 35.45}{hour})$ (104 hours)

=7,373.60$

$Solar\ EMERGY = (7{,}373.60\$)(2.00\ x10^{12}\frac{sej}{\$})$

=1.47 $x10^{16} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 104

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$\ 47.50}{hour})$ (104 hours)

=19,760$

$Solar\ EMERGY = (19{,}760\$)(2.00\ x10^{12}\frac{sej}{\$})$

=3.95 $x10^{16} se\ j$

S1.4 Twenty Six Truck Drivers

Labor Hours = 104

Salary = \$ 36.60

$Raw\ Units = (26)(\frac{\$\ 36.60}{hour})$ (104 hours)

=98,966.40\$

$Solar\ EMERGY = (98{,}966.40\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=1.98\ x10^{17} se\ j$

Subgrade Sealant

Crew type is B-45

1-Equipment Operator \$ 47.50

1-Truck Driver \$ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$Quantity = (80\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$

$= 46{,}933.3\ SY$

$Mass = (46{,}933.3\ SY)(0.2\frac{gallon}{SY})$

$= 9{,}386.7\ gallons$

Rate $= (46{,}933.3\ SY)(\frac{1\ day}{5{,}000\ SY})$

$= 9.4\ days\left(8\frac{hrs}{day}\right)$

$= 75.2\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(75.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$=89.95x10^9 J$$

$$Solar\ EMERGY = (89.95\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 5.94x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 75.2 hours

$$Raw\ Units = (75.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 119.39x10^3 g$$

$$Solar\ EMERGY = (119.39x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 8.00x10^{14}\ sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12} \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 75.2

Salary = \$ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (75.2hours)

=3,572\$

$Solar\ EMERGY = (3{,}572\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

$= 7.14\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 75.2

Salary = \$ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (75.2 hours)

=2,752.32\$

$Solar\ EMERGY = (2{,}752.32\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=5.50\ x10^{15} se\ j$

Table IH-17: Construction Phase F
6.5 Inches of Asphalt Concrete Pavement Type B25.OC

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$1.20x10^{9}J$		$7.99x10^{14}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$1.20x10^{9}J$	$6.66x10^{5}$	7.99 $x10^{14}$ sej
E-6	Materials	N/A		
F	FUEL ENERGY	$3.36x10^{12}J$		$2.22x10^{17}$sej
F-1	Equipment	$3.36x10^{12}J$	$6.6x10^{4}$	2.22 $x10^{17}$sej
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$3.83x10^{6}g$		$2.57x10^{16}\ sej$
G-1	Equipment	$3.83x10^{6}g$	$6.7x10^{9}$	$2.57x10^{16}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	184,284.88$		$3.69x10^{17}sej$
S-1	Labor	184,284.88$	$2.00x10^{12}$	3.69 $x10^{17}sej$
S-2	Materials	N/A		

Table IH-17: Construction Phase F
6.5 Inches of Asphalt Concrete Pavement Type B25.OC

Material: Asphalt Concrete

Place in two layers; each at a rate of 370.5 lb/SY or 3.25 inches thick

$$Quantity = (2)(76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)(370.5\frac{lb}{SY})$$

$$= 33.04\ x10^6 lbs.\left(\frac{1\ Ton}{2{,}000\ lbs.}\right)$$

$$= 16.52\ x10^3 Tons$$

Rate $= (89.17\ x10^3 SY)(\frac{1\ day}{4{,}520\ SY})$

$$= 19.7\ days\left(8\frac{hrs}{day}\right)$$

$$= 157.6\ hours$$

Hauling Duration $= 16.52\ x10^3 Tons\ (\frac{1\ truck}{16} tons)$

$$= say\ 1{,}033\ trips$$

$$= \frac{1{,}033\ trips}{20\ days}$$

$$= \frac{52\ trips}{day}$$

Each dump truck has a capacity of ~ 16 tons, so hauling duration and frequency is:

Haul distance is 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 13 trucks.

Crew type is B-25 Modified

1-Labor Foreman $ 37.45

7-Laborers $ 35.45 per hour

3-Equipment Operators $ 47.50 per hour

14-Truck Drivers $ 36.60

Equipment type

1-Paver (39,044 pounds)

1-Tandem asphalt roller (23,525 pounds)

1-Asphalt wheel roller (28,535 pounds)

13-Dump trucks (25,000 pounds)

1-Water Truck (25,000 pounds)

Environment

E5. Water

E.5 1,600 gal/day per roller

Volume= $(2)(20\ days)(1{,}600\ \frac{gal}{day})$

$= 64{,}000\ gallons$

$Raw\ Units = (64{,}000\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$

$= 1.20\ x10^{9}J$

$Solar\ EMERGY = (1.20\ x10^{9}J)(6.66x10^{5}\ \frac{sej}{J})$

$= \ 7.99x10^{14}\ sej$

Fuel Energy

Petroleum Transformity $= 6.6x10^{4}\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Paver (39,044 Lbs.)

Fuel consumption = 3.0 gal/hour

$Raw\ Units = (3.0\ \frac{gal}{hour})(157.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$

$=70.69x10^{9}J$

$Solar\ EMERGY = (70.69\ x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$

$= \ 4.67x10^{15}\ sej$

F1.2 One Tandem Asphalt Roller (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = (2.5\ \frac{gal}{hour})(157.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$=58.91x10^9 J$$

$$Solar\ EMERGY = (58.91\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 3.89x10^{15}\ sej$$

F1.3 Asphalt wheel roller (28,535 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units =\ (3.5\ \frac{gal}{hour})(157.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 82.48\ x10^9 J$$

$$Solar\ EMERGY = (82.48x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 5.44x10^{15}\ sej$$

F1.4 Thirteen Dump trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (13)(8\ \frac{gal}{hour})(157.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 2.45\ x10^{12} J$$

$$Solar\ EMERGY = (2.45x10^{12} J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 1.62x10^{17}\ sej$$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(157.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 188.52\ x10^9 J$$

$$Solar\ EMERGY = (188.52\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 1.24x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Paver

Weight = 39,044 Lbs.

Useful Life = 10,000 hours

Use = 157.6 hours

$$Raw\ Units = (157.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(39{,}044\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 279.12x10^{3}g$$

$$Solar\ EMERGY = (279.12x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.87\ x10^{15}sej$$

G1.2 One Tandem Asphalt Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 157.6 hours

$$Raw\ Units = (157.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 168.17x10^{3}g$$

$$Solar\ EMERGY = (168.17x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.13\ x10^{15}sej$$

G1.3 Asphalt Wheel Roller

Weight = 28,535 Lbs.

Useful Life = 10,000 hours

Use = 157.6 hours

$Raw\ Units = (157.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(28{,}535\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 203.99x10^{3}g$

$Solar\ EMERGY = (203.99x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 1.37\ x10^{15}sej$

G1.4 Thirteen Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 157.6 hours

$Raw\ Units = (13)(157.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 2.32x10^{6}g$

$Solar\ EMERGY = (2.32x10^{6}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 1.55\ x10^{16}sej$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 157.6 hours

$Raw\ Units = (157.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 178.72x10^{3}g$

$Solar\ EMERGY = (178.72x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 1.2x10^{15}sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 157.6

Salary = \$ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (157.6 hours)

=5,902.12\$

$Solar\ EMERGY = (5{,}902.12\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

$= 1.18\ x10^{16} se\ j$

S1.2 Seven Laborers

Labor Hours = 157.6

Salary = \$ 35.45

$Raw\ Units = (7)(\frac{\$\ 35.45}{hour})$ (157.6 hours)

=39,108.44\$

$Solar\ EMERGY = (39{,}108.44\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=7.82\ x10^{16} se\ j$

S1.3 Three Equipment Operators

Labor Hours = 157.6

Salary = \$ 47.50

$Raw\ Units = (3)(\frac{\$47.50}{hour})$ (157.6 hours)

=22,458\$

$Solar\ EMERGY = (22{,}458\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 4.49\ x10^{16} se\ j$

S1.4 Fourteen Truck Drivers

Labor Hours = 157.6

Salary = $ 47.50

$Raw\ Units = (14)(\frac{\$\ 36.60}{hour})$ (157.6hours)

=80,754.24$

$Solar\ EMERGY = (80{,}754.24\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=1.62\ x10^{17} se\ j$

Prime Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = 3(76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 133{,}760\ SY$$

$$Mass = (133{,}760\ SY)(0.35\frac{gallon}{SY})$$

$$= 46{,}816\ gallons$$

Rate $= (133{,}760\ SY)\left(\frac{1\ day}{5{,}000\ SY}\right)$

$= 26.8\ days\left(8\frac{hrs}{day}\right)$

$= 214.4\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(214.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$=256.46x10^9 J$$

$$Solar\ EMERGY = (256.46\ x10^9 J)(6.6x10^4\frac{sej}{J})$$

$$=\ 1.69x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 214.4 hours

$$Raw\ Units = (214.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 340.38x10^3 g$

$$Solar\ EMERGY = (340.38x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 2.28x10^{15}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 214.4

Salary = \$ 47.50

$$Raw\ Units = (\frac{\$47.50}{hour})\ (214.4\ \text{hours})$$

=10,184\$

$$Solar\ EMERGY = (10{,}184\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

$= 2.04\ x10^{16} se\ j$

S1.2 One Truck Driver

Labor Hours = 214.4

Salary = \$ 36.60

$$Raw\ Units = (\frac{\$\ 36.60}{hour})\ (214.4\ \text{hours})$$

=7,847.04\$

$$Solar\ EMERGY = (7{,}847.04\$)(2.00\ x10^{12}\frac{sej}{\$})$$

$=1.57\ x10^{16} se\ j$

Tack Coat

Crew type is B-45

1-Equipment Operator \$ 47.50

1-Truck Driver \$ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = 3(76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 133{,}760\ SY$$

$$Mass = (133{,}760\ SY)(0.06\frac{gallon}{SY})$$

$$= 8{,}025.6\ gallons$$

Rate $= (133{,}760\ SY)(\frac{1\ day}{5{,}000\ SY})$

$$= 26.8\ days\left(8\frac{hrs}{day}\right)$$

$$= 214.4\ hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(214.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$=256.46x10^{9}J$

$$Solar\ EMERGY = (256.46\ x10^{9}J)(6.6x10^{4}\frac{sej}{J})$$

$$= 1.69x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 214.4 hours

$$Raw\ Units = (214.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 340.38x10^{3}g$

$$Solar\ EMERGY = (340.38x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 2.28x10^{15}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 214.4

Salary = \$ 47.50

$$Raw\ Units = (\frac{\$47.50}{hour})\ (214.4\ \text{hours})$$

=10,184\$

$Solar\ EMERGY = (10{,}184\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 2.04\ x10^{16} se\ j$

S1.2 One Truck Driver

Labor Hours = 214.4

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})\ (214.4\ \text{hours})$

$=7{,}847.04\$$

$Solar\ EMERGY = (7{,}847.04\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=1.57\ x10^{16} se\ j$

Table IH-18: Construction Phase F
3 Inches of Asphalt Concrete Pavement Type I19.OC

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$5.98x10^{8}J$		$3.99x10^{14}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$5.98\ x10^{8}$	$6.66x10^{5}$	$3.99\ x10^{14}sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$1.51x10^{12}J$		$9.98x10^{16}sej$
F-1	Equipment	$1.51x10^{12}J$	$6.60x10^{4}$	$9.98x10^{16}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$1.72x10^{6}g$		$1.15x10^{16}sej$
G-1	Equipment	$1.72x10^{6}g$	$6.70x10^{9}$	$1.15x10^{16}$sej
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	83,564.72$		$1.67x10^{17}sej$
S-1	Labor	83,564.72$	$2.00x10^{12}$	$1.67x10^{17}sej$
S-2	Materials	N/A		

Table IH-18: Construction Phase F
3 Inches of Asphalt Concrete Pavement Type I19.OC

Material: Asphalt Concrete

Place in one layer at a rate of 342 lb/SY or 3 inches thick

$$Quantity = (76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)(342\frac{lb}{SY})$$

$$= 15.25\ x10^6 lbs.\left(\frac{1\ Ton}{2{,}000\ lbs.}\right)$$

$$= 7.63\ x10^3 Tons$$

$$\text{Rate} \quad = (44.59\ x10^3 SY)(\frac{1\ day}{4{,}520\ SY})$$

$$= 9.9\ days\left(8\frac{hrs}{day}\right)$$

$$= 79.2\ hours$$

$$\text{Hauling Duration} = 7.63\ x10^3 Tons\ (\frac{1\ truck}{16} tons)$$

$$= say\ 477\ trips$$

$$= \frac{477\ trips}{10\ days}$$

$$= \frac{48\ trips}{day}$$

Each dump truck has a capacity of ~ 16 tons, so hauling duration and frequency is:

Haul distance is 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 12 trucks.

Crew type is B-25 Modified

1-Labor Foreman $ 37.45

7-Laborers $ 35.45 per hour

3-Equipment Operators $ 47.50 per hour

13-Truck Drivers $ 36.60

Equipment type

1-Paver (39,044 pounds)

1-Tandem asphalt roller (23,525 pounds)

1-Asphalt wheel roller (28,535 pounds)

13-Dump trucks (25,000 pounds)

1-Water Truck (25,000 pounds)

Environment

E5. Water

E.5 1,600 gal/day per roller

Volume= $(2)(10\ days)(1{,}600\ \frac{gal}{day})$

$$= 32{,}000\ gallons$$

$$Raw\ Units = (32{,}000\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^1$$

$$= 598.4\ x10^6 J$$

$$Solar\ EMERGY = (598.4\ x10^6 J)(6.66x10^5\ \frac{sej}{J})$$

$$= 3.99x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity $= 6.6x10^4\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Paver (39,044 Lbs.)

Fuel consumption = 3.0 gal/hour

$$Raw\ Units = (3.0\ \frac{gal}{hour})(79.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$=35.53x10^9 J$$

$$Solar\ EMERGY = (35.53\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= 2.35x10^{15}\ sej$$

F1.2 One Tandem Asphalt Roller (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = (2.5\ \frac{gal}{hour})(79.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\,\frac{J}{barrel}\right)^{1}$$

$$=29.61x10^{9}J$$

$$Solar\ EMERGY = (29.61\ x10^{9}J)(6.6x10^{4}\,\frac{sej}{J})$$

$$=\ \ 1.95x10^{15}\ sej$$

F1.3 Asphalt wheel roller (28,535 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = \ (3.5\ \frac{gal}{hour})(79.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\,\frac{J}{barrel}\right)^{1}$$

$$= 41.45\ x10^{9}J$$

$$Solar\ EMERGY = (41.45x10^{9}J)(6.6x10^{4}\,\frac{sej}{J})$$

$$=\ \ 2.74x10^{15}\ sej$$

F1.4 Dump trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (12)(8\ \frac{gal}{hour})(79.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\,\frac{J}{barrel}\right)^{1}$$

$$= 1.14\ x10^{12}J$$

$$Solar\ EMERGY = (1.14x10^{12}J)(6.6x10^{4}\,\frac{sej}{J})$$

$$=\ \ 7.52x10^{16}\ sej$$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(79.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\,\frac{J}{barrel}\right)^{1}$$

$$= 94.74\ x10^{9}J$$

$$Solar\ EMERGY = (94.74\ x10^{9}J)(6.6x10^{4}\,\frac{sej}{J})$$

$$=\ \ 6.25x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Paver

Weight = 39,044 Lbs.

Useful Life = 10,000 hours

Use = 79.2 hours

$$Raw\ Units = (79.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(39{,}044\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 140.27x10^{3}g$$

$$Solar\ EMERGY = (140.27x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 9.40\ x10^{14}sej$$

G1.2 One Tandem Asphalt Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 79.2 hours

$$Raw\ Units = (79.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 84.51x10^{3}g$$

$$Solar\ EMERGY = (84.51x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.66\ x10^{14}sej$$

G1.3 Asphalt Wheel Roller

Weight = 28,535 Lbs.

Useful Life = 10,000 hours

Use = 79.2 hours

$$Raw\ Units = (79.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(28{,}535\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 102.51x10^{3}g$

$$Solar\ EMERGY = (102.51x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 6.87\ x10^{14}sej$

G1.4 Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 79.2hours

$$Raw\ Units = (12)(79.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 1.08x10^{6}g$

$$Solar\ EMERGY = (1.08x10^{6}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 7.24\ x10^{15}sej$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 79.2 hours

$$Raw\ Units = (79.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 89.81x10^{3}g$

$$Solar\ EMERGY = (89.81x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 6.02x10^{14}sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 79.2

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (79.2 hours)

=2,966.04$

$Solar\ EMERGY = (2{,}966.04\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

= 5.93 $x10^{15} se\ j$

S1.2 Seven Laborers

Labor Hours = 79.2

Salary = $ 35.45

$Raw\ Units = (7)(\frac{\$\ 35.45}{hour})$ (79.2 hours)

=19,653.48$

$Solar\ EMERGY = (19{,}653.48\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=3.93 $x10^{16} se\ j$

S1.3 Three Equipment Operators

Labor Hours = 79.2

Salary = $ 47.50

$Raw\ Units = (3)(\frac{\$47.50}{hour})$ (79.2 hours)

=11,286$

$Solar\ EMERGY = (11{,}286\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 2.26\ x10^{16} se\ j$

S1.4 Thirteen Truck Drivers

Labor Hours = 79.2

Salary = $ 47.50

$Raw\ Units = (13)(\frac{\$\ 36.60}{hour})$ (79.2hours)

=37,683.36$

$Solar\ EMERGY = (37{,}683.36\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=7.54\ x10^{16} se\ j$

Prime Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 44{,}586.7\ SY$$

$$Mass = (44{,}586.7\ SY)(0.35\frac{gallon}{SY})$$

$= 15{,}605.3\ gallons$

Rate $= (44{,}586.7\ SY)(\frac{1\ day}{5{,}000\ SY})$

$= 8.9\ days\left(8\frac{hrs}{day}\right)$

$= 71.2\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$Raw\ Units = (8.0\ \frac{gal}{hour})(71.2\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$

$=85.17x10^9J$

$Solar\ EMERGY = (85.17\ x10^9J)(6.6x10^4\frac{sej}{J})$

$= 5.62x10^{15}\ sej$

Goods

Machinery Transformity$= 6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 71.2 hours

$$Raw\ Units = (71.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 113.04x10^{3}g$

$$Solar\ EMERGY = (113.04x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 7.57x10^{14}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours =71.2

Salary = $ 47.50

$$Raw\ Units = (\frac{\$47.50}{hour})\ (71.2\ \text{hours})$$

=3,382$

$$Solar\ EMERGY = (3{,}382\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$= 6.76\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 71.2

Salary = $ 36.60

$$Raw\ Units = (\frac{\$\ 36.60}{hour})\ (71.2\ \text{hours})$$

=2,605.92$

$$Solar\ EMERGY = (2{,}605.92\$)(2.00\ x10^{12}\ \frac{sej}{\$})$$

$=5.21\ x10^{15} se\ j$

Tack Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (76\,ft)(5{,}280\,ft)\left(\frac{1\,SY}{9\,sf}\right)$$

$$= 44{,}586.7\,SY$$

$$Mass = (44{,}586.7\,SY)(0.06\frac{gallon}{SY})$$

$$= 2{,}675.20\,gallons$$

Rate $= (44{,}586.7\,SY)(\frac{1\,day}{5{,}000\,SY})$

$$= 8.9\,days\left(8\frac{hrs}{day}\right)$$

$$= 71.2\,hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\,\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\,\frac{gal}{hour})(71.2\,hours)\left(\frac{barrel}{42\,gal}\right)\left(6.28x10^9\,\frac{J}{barrel}\right)^1$$

$=85.17x10^9 J$

$$Solar\ EMERGY = (85.17\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= 5.62x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 71.2 hours

$$Raw\ Units = (71.2\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 113.04x10^3 g$

$$Solar\ EMERGY = (113.04x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 7.57x10^{14}\ sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12} \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours =71.2

Salary = \$ 47.50

$$Raw\ Units = (\frac{\$47.50}{hour})\ (71.2\ \text{hours})$$

=3,382\$

$$Solar\ EMERGY = (3{,}382\$)\ (2.00\ x10^{12} \frac{sej}{\$})$$

$= 6.76\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 71.2

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (71.2 hours)

=2,605.92$

$Solar\ EMERGY = (2{,}605.92\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=5.21\ x10^{15} se\ j$

Table IH-19: Construction Phase F
3 Inches of Asphalt Concrete Pavement Type S9.5C

	Phase-F Construction Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$1.63x10^{9}J$		$1.09x10^{15}sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$1.63x10^{9}J$	$6.66x10^{5}$	$1.09x10^{15}sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$1.99x10^{12}J$		$1.31x10^{17}sej$
F-1	Equipment	$1.99x10^{12}J$	$6.6x10^{4}$	$1.31x10^{17}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.53x10^{6}g$		$1.70x10^{16}$sej
G-1	Equipment	$2.53x10^{6}g$	$6.7x10^{9}$	$1.70x10^{16}sej$
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	136,430.72$		$2.73x10^{17}sej$
S-1	Labor	136,430.72$	$2.00x10^{12}$	$2.73x10^{17}$sej
S-2	Materials	N/A		

Table IH-19: Construction Phase F
3 Inches of Asphalt Concrete Pavement Type S9.5C

Material: Asphalt Concrete

Place in two layers; each at a rate of 168 lb/SY or 1.5 inches thick

$$Quantity = (2)(76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)(168\frac{lb}{SY})$$

$$= 14.98\ x10^6 lbs.\left(\frac{1\ Ton}{2{,}000\ lbs.}\right)$$

$$= 7.49\ x10^3 Tons$$

Rate $= (89.17\ x10^3 SY)(\frac{1\ day}{4{,}900\ SY})$

$$= 18.2\ days\left(8\frac{hrs}{day}\right)$$

$$= 145.6\ hours$$

Hauling Duration $= 7.49\ x10^3 Tons\ (\frac{1\ truck}{16} tons)$

$$= say\ 468\ trips$$

$$= \frac{468\ trips}{18.2\ days}$$

$$= \frac{26\ trips}{day}$$

Each dump truck had a capacity of ~ 16 tons, so hauling duration and frequency was:

Haul distance was 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 7 trucks.

Crew type is B-25B Modified

1-Labor Foreman $ 37.45

7-Laborers $ 35.45 per hour

4-Equipment Operators $ 47.50 per hour

8-Truck Drivers $ 36.60

Equipment type

1-Paver (39,044 pounds)

2-Tandem asphalt Rollers (23,525 pounds)

1-Asphalt wheel roller (28,535 pounds)

7-Dump trucks (25,000 pounds)

1-Water Truck (25,000 pounds)

Environment

E5. Water

E.5 1,600 gal/day per roller

Volume= $(3)(18.2\ days)(1{,}600\ \frac{gal}{day})$

$$= 87{,}360\ gallons$$

$$Raw\ Units = (87{,}360\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$$

$$= 1.63\ x10^{9}J$$

$$Solar\ EMERGY = (1.63\ x10^{9}J)(6.66x10^{5}\ \frac{sej}{J})$$

$$= \ 1.09x10^{15}\ sej$$

Fuel Energy

Petroleum Transformity $= 6.6x10^{4}\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Paver (39,044 Lbs.)

Fuel consumption = 3.0 gal/hour

$$Raw\ Units = (3.0\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

$$=65.31x10^{9}J$$

$$Solar\ EMERGY = (65.31\ x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$$

$$= \ 4.31x10^{15}\ sej$$

F1.2 Two Tandem Asphalt Rollers (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = (2)(2.5\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\frac{J}{barrel}\right)^{1}$$

$$=108.85x10^{9}J$$

$$Solar\ EMERGY = (108.85\ x10^{9}J)(6.6x10^{4}\frac{sej}{J})$$

$$=\ 7.18x10^{15}\ sej$$

F1.3 Asphalt wheel roller (28,535 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (3.5\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\frac{J}{barrel}\right)^{1}$$

$$= 76.20\ x10^{9}J$$

$$Solar\ EMERGY = (76.20x10^{9}J)(6.6x10^{4}\frac{sej}{J})$$

$$=\ 5.03x10^{15}\ sej$$

F1.4 Seven Dump Trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (7)(8\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\frac{J}{barrel}\right)^{1}$$

$$= 1.22\ x10^{12}J$$

$$Solar\ EMERGY = (1.22x10^{12}J)(6.6x10^{4}\frac{sej}{J})$$

$$=\ 8.05x10^{16}\ sej$$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\frac{J}{barrel}\right)^{1}$$

$$= 174.17\ x10^{9}J$$

$$Solar\ EMERGY = (174.17\ x10^{9}J)(6.6x10^{4}\frac{sej}{J})$$

$$=\ 1.15x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Paver

Weight = 39,044 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(39{,}044\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 257.86x10^3 g$$

$$Solar\ EMERGY = (257.86x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.73\ x10^{15} sej$$

G1.2 Two Tandem Asphalt Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (2)(145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 310.74x10^3 g$$

$$Solar\ EMERGY = (310.74x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 2.08\ x10^{15} sej$$

G1.3 Asphalt Wheel Roller

Weight = 28,535 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(28{,}535\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 188.46x10^3 g$$

$$Solar\ EMERGY = (188.46x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.26x10^{15} sej$$

G1.4 Seven Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (7)(145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 1.16x10^6 g$$

$$Solar\ EMERGY = (1.16x10^6 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 7.77\ x10^{15} sej$$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 165.11x10^3 g$$

$$Solar\ EMERGY = (165.11x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.11x10^{15} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 145.6

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (145.6 hours)

=5,452.72$

$Solar\ EMERGY\ = (5{,}452.72\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

= 1.09 $x10^{16} se\ j$

S1.2 Seven Laborers

Labor Hours = 145.6

Salary = $ 35.45

$Raw\ Units = (7)(\frac{\$\ 35.45}{hour})$ (145.6 hours)

=36,130.64$

$Solar\ EMERGY\ = (36{,}130.64\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

=7.23 $x10^{16} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 145.6

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$47.50}{hour})$ (145.6 hours)

=27,664$

$Solar\ EMERGY = (27{,}664\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 5.53\ x10^{16} se\ j$

S1.4 Eight Truck Drivers

Labor Hours = 145.6

Salary = $ 47.50

$Raw\ Units = (8)(\frac{\$\ 36.60}{hour})$ (145.6 hours)

=42,631.68$

$Solar\ EMERGY = (42{,}631.68\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=8.53\ x10^{16} se\ j$

Prime Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = 2((76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right))$$

$$= 89{,}173.3\ SY$$

$Mass = (89{,}173.3\ SY)(0.35 \frac{gallon}{SY})$

$= 31{,}210.7\ gallons$

Rate $= (89{,}173.3\ SY)(\frac{1\ day}{5{,}000\ SY})$

$= 17.8\ days \left(8 \frac{hrs}{day}\right)$

$= 142.4\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$Raw\ Units = (8.0\ \frac{gal}{hour})(142.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$

$=170.34x10^9 J$

$Solar\ EMERGY = (170.34\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= 1.12x10^{16}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 142.4 hours

$Raw\ Units = (142.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 226.07x10^{3}g$

$Solar\ EMERGY = (226.07x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 1.51x10^{15}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 142.4

Salary = $ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (142.4 hours)

=6,764$

$Solar\ EMERGY = (6{,}764\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 1.35\ x10^{16}se\ j$

S1.2 One Truck Driver

Labor Hours = 142.4

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (142.4 hours)

=5,511.84$

$Solar\ EMERGY = (5{,}211.84\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=1.04\ x10^{16} se\ j$

Tack Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = 2((76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right))$$

$$= 89{,}173.3\ SY$$

$$Mass = (89{,}173.3\ SY)(0.06\frac{gallon}{SY})$$

$$= 5{,}350.4\ gallons$$

Rate $= (89{,}173.3\ SY)(\frac{1\ day}{5{,}000\ SY})$

$= 17.8\ days\left(8\frac{hrs}{day}\right)$

$= 142.4\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^{4}\,\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(142.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\,\frac{J}{barrel}\right)^{1}$$

$$=170.34x10^{9}J$$

$$Solar\ EMERGY = (170.34\ x10^{9}J)(6.6x10^{4}\,\frac{sej}{J})$$

$$=\ 1.12x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 142.4 hours

$$Raw\ Units = (142.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 226.07x10^{3}g$$

$$Solar\ EMERGY = (226.07x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.51x10^{15}\ sej$$

Services

Service/Labor Transformity = $2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 142.4

Salary = $ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (142.4 hours)

=6,764$

$Solar\ EMERGY\ = (6{,}764\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 1.35\ x10^{16} se\ j$

S1.2 One Truck Driver

Labor Hours = 142.4

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (142.4 hours)

=5,511.84$

$Solar\ EMERGY\ = (5{,}211.84\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=1.04\ x10^{16} se\ j$

Table IH-20: Use Phase - G
Use Phase at Year-12

		Phase-G Use Environmental Value Engineering EMERGY Analysis Input Table		
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$6.00\ x10^{8} J$		$3.99\ x10^{14} sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$6.00\ x10^{8} J$	$6.66\ x10^{5}$	$3.99\ x10^{14} sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$6.50\ x10^{12} J$		$4.31\ x10^{17} sej$
F-1	Equipment	$6.50\ x10^{12} J$	$6.6\ x10^{4}$	$4.31\ x10^{17} sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$1.41\ x10^{6} g$		$9.48\ x10^{15}$sej
G-1	Equipment	$1.41\ x10^{6} g$	$6.7\ x10^{9}$	$9.48\ x10^{15} sej$
G-2	Facilities			
G-3	Goods			
G-4	Tools			
S	SERVICES	66,568.80$		$1.33\ x10^{17} sej$
S-1	Labor	66,568.80$	$2.00\ x10^{12}$	$1.33\ x10^{17} sej$
S-2	Materials	N/A		

Table IH-20: Use Phase - G
Use Phase at Year-12

Mill and replace 1.5 inches of surface course and fog seal shoulders

Milling

Crew B-71

1-Outside labor foreman $ 37.45

3-Laborers $ 35.45

3-Equipment Operators $ 47.50

8-Truck Driver $ 36.60

Equipment

1-Cold Planer (86,360 pounds)

1-Road Sweeper (4,200 pounds)

1-Wheel Loader (24,251 pounds)

1-Water Truck (25,000 pounds)

7-Dump Trucks (25,000 pounds)

Milling duration based on 6,000 SY/day.

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28.16\ x10^3 SY$$

$$Mass = (28.16\ x10^3 SY)(168\frac{lb}{SY})$$

$$= (4.73\ x10^6 Lbs.)(\frac{1\ Ton}{2{,}000\ Lbs.})$$

$$= 2.37\ x10^3 Tons$$

Milling Duration $= (28.16\ x10^3 SY)(\frac{1\ day}{6{,}000\ SY})$

$$= 4.7\ days$$

$= 37.6$ hours

Hauling Duration $= 2.37\ x10^3 Tons\ (\frac{1\ truck}{16}tons)$

$$= say\ 148\ trips$$

$$= \frac{148\ trips}{4.7\ days}$$

$$= \frac{32\ trips}{day}$$

Each dump truck has a capacity of ~ 16 tons, so hauling duration and frequency is:

Haul distance is 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 8 trucks.

Environment

E5. Water

E.5.1 Water Transformity = $6.66\ x10^5\ \frac{sej}{J}$

1,000 gal/day (4.7 days) = 4,700 gallons

$$Raw\ Units = (4{,}700\ gal)\left(3.7854\frac{l}{gal}\right)\left(\frac{1{,}000\ g}{l}\right)\left(4.94\frac{J}{g}\right)^1$$

$= 87.89x10^6J$

$$Solar\ EMERGY = (87.89x10^6J)(6.66x10^5\frac{sej}{J})$$

$$= \ 5.85x10^{13}\ sej$$

Fuel Energy

Petroleum Transformity $= 6.6x10^4\frac{sej}{J}$

F1. Equipment

F1.1 One Cold Planer

Fuel consumption = 25 gal/hour

Use = $37.6\ hour$

$$Raw\ Units = (25\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 140.55\ x10^9J$

$Solar\ EMERGY = (140.55\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 9.28x10^{15}\ sej$

F1.2 One Road Sweeper

Fuel consumption = 1.5 gal/hour

Use = $37.6\ hour$

$$Raw\ Units = (1.5\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

= $8.43\ x10^9 J$

$Solar\ EMERGY = (8.43\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 5.56x10^{14}\ sej$

F1.3 One Wheel Loader

Fuel consumption = 3.5 gal/hour

Use = $37.6\ hour$

$$Raw\ Units = (3.5\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

= $19.68\ x10^9 J$

$Solar\ EMERGY = (19.68\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 1.30x10^{15}\ sej$

F1.4 One Water Truck

Fuel consumption = 8 gal/hour

Use = $37.6\ hour$

$$Raw\ Units = (8\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

= $44.98\ x10^9 J$

$Solar\ EMERGY = (44.98\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \; 2.97x10^{15}\; sej$

F1.4 Eight Dump Trucks

Fuel consumption = 8 gal/hour

Use = 37.6 $hour$

$$Raw\ Units = (8)(8\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$$

= 359.81 $x10^{9}J$

$$Solar\ EMERGY = (359.81\ x10^{9}J)(6.6x10^{4}\ \frac{sej}{J})$$

$= \; 2.37x10^{16}\; sej$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 One Cold Planer

Weight = 86,360 LB

Useful Life = 10,000 hours

Use =37.6 hour

$$Raw\ Units = (37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(86{,}360\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

= $147.29x10^{3}g$

$$Solar\ EMERGY = (147.29x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 9.87\ x10^{14}sej$

G1.2 One Road Sweeper

Weight = 4,200 LB

Useful Life = 10,000 hours

Use =37.6 hour

$Raw\ Units = (37.6hour)\left(\frac{1}{10{,}000\ hours}\right)(4{,}200\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 7.16x10^{3}g$

$Solar\ EMERGY = (7.16x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 4.80\ x10^{13}sej$

G1.3 One Wheel Loader

Weight = 24,251 LB

Useful Life = 10,000 hours

Use =37.6 hour

$Raw\ Units = (37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 41.36x10^{3}g$

$Solar\ EMERGY = (41.36x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 2.77\ x10^{14}sej$

G1.4 One Water Truck

Weight = 25,000 LB

Useful Life = 10,000 hours

Use =37.6 hour

$Raw\ Units = (37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 42.64x10^{3}g$

$Solar\ EMERGY = (42.64x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 2.86x10^{14}$

G1.5 Eight Dump Trucks

Weight = 25,000 LB

Useful Life = 10,000 hours

Use =37.6 hour

$$Raw\ Units = (8)(37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 341.11x10^{3}g$

$$Solar\ EMERGY = (341.11x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 2.29\ x10^{15}sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One outside labor foreman

Labor Hours = 37.6

Salary = \$ 37.45

$$Raw\ Units = (\frac{\$\ 37.45}{hour})\ (37.6\ \text{hour})$$

=1,408.12\$

$$Solar\ EMERGY = (1{,}408.12\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

$= 2.82\ x10^{15}se\ j$

S1.2 Three laborers

Labor Hours = 37.6

Salary = \$ 35.45

$$Raw\ Units = (3)(\frac{\$\ 35.45}{hour})\ (37.6\ \text{hours})$$

=3,998.76\$

$$Solar\ EMERGY = (3{,}998.76\$)(2.00\ x10^{12}\frac{sej}{\$})$$

$=8.00\ x10^{15} se\ j$

S1.3 Three equipment operators

Labor Hours = 37.6

Salary = \$ 47.50

$Raw\ Units = (3)(\frac{\$\ 47.50}{hour})\ (37.6\ \text{hours})$

=5,358\$

$Solar\ EMERGY = (5{,}358\$)\ (2.00\ x10^{12} \frac{sej}{\$})$

$=1.07\ x10^{16} se\ j$

S1.4 Eight Truck Drivers

Labor Hours = 37.6

Salary = \$ 36.60

$Raw\ Units = (8)(\frac{\$\ 36.60}{hour})\ (37.6\ \text{hours})$

=11,009.28\$

$Solar\ EMERGY = (11{,}009.28\$)\ (2.00\ x10^{12} \frac{sej}{\$})$

$=2.20\ x10^{16} se\ j$

Place 1.5 Inches of Type S9.5C

Crew type is B-25B Modified

1-Labor Foreman \$ 37.45

7-Laborers \$ 35.45 per hour

4-Equipment Operators \$ 47.50 per hour

8-Truck Drivers \$ 36.60

Equipment type

1-Paver (39,044 pounds)

2-Tandem asphalt Rollers (23,525 pounds)

1-Asphalt wheel roller (28,535 pounds)

7-Dump trucks (25,000 pounds)

1-Water Truck (25,000 pounds)

$$Quantity = (48ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28.16\ x10^3 SY$$

$$Mass = (28.16\ x10^3 SY)(168\frac{lb}{SY})$$

$$= (4.73\ x10^6 Lbs.)(\frac{1\ Ton}{2{,}000\ Lbs.})$$

$$= 2.37\ x10^3 Tons$$

$$\text{Rate} \quad = (28.16\ x10^3 SY)(\frac{1\ day}{4{,}900\ SY})$$

$$= 5.7\ days\left(8\frac{hrs}{day}\right)$$

$$= 45.6\ hours$$

$$\text{Hauling Duration} = 2.37\ x10^3 Tons\ (\frac{1\ truck}{16}tons)$$

$$= say\ 148\ trips$$

$$= \frac{148\ trips}{5.7\ days}$$

$$= \frac{26\ trips}{day}$$

Each dump truck has a capacity of ~ 16 tons, so hauling duration and frequency is:

Haul distance is 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 7 trucks.

Environment

E5. Water

E.5 1,600 gal/day per roller

Volume= $(3)(5.7\ days)(1{,}600\ \frac{gal}{day})$

$= 27{,}360\ gallons$

$Raw\ Units = (27{,}360\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^1$

$= 511.63\ x10^6 J$

$Solar\ EMERGY = (511.63\ x10^6 J)(6.66x10^5\ \frac{sej}{J})$

$= \ 3.41x10^{14}\ sej$

Fuel Energy

Petroleum Transformity = $6.6x10^4\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Paver (39,044 Lbs.)

Fuel consumption = 3.0 gal/hour

$Raw\ Units = (3.0\ \frac{gal}{hour})(45.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$

$=20.45x10^9 J$

$Solar\ EMERGY = (20.45\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$

$= \ 1.35x10^{15}\ sej$

F1.2 Two Tandem Asphalt Rollers (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$Raw\ Units = (2)(2.5\ \frac{gal}{hour})(45.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$

$=34.09x10^9 J$

$Solar\ EMERGY = (34.09\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$

$= \ 2.25x10^{15}\ sej$

F1.3 Asphalt wheel roller (28,535 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (3.5\ \frac{gal}{hour})(45.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 23.86\ x10^9 J$$

$$Solar\ EMERGY = (23.86x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 1.57x10^{15}\ sej$$

F1.4 Seven Dump trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (7)(8\ \frac{gal}{hour})(45.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 381.82\ x10^9 J$$

$$Solar\ EMERGY = (381.82x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 2.52x10^{16}\ sej$$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(45.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 54.55\ x10^9 J$$

$$Solar\ EMERGY = (54.55\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$= \ 3.60x10^{15}\ sej$$

Goods

Machinery Transformity= 6.7 $x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Paver

Weight = 39,044 Lbs.

Useful Life = 10,000 hours

Use = 45.6 hours

$$Raw\ Units = (45.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(39{,}044\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 80.76x10^{3}g$

$$Solar\ EMERGY = (80.76x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.41\ x10^{14}sej$$

G1.2 Two Tandem Asphalt Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 45.6 hours

$$Raw\ Units = (2)(45.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 97.32x10^{3}g$

$$Solar\ EMERGY = (97.32x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 6.52\ x10^{14}sej$$

G1.3 Asphalt Wheel Roller

Weight = 28,535 Lbs.

Useful Life = 10,000 hours

Use = 45.6 hours

$$Raw\ Units = (45.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(28{,}535\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 59.02x10^{3}g$

$$Solar\ EMERGY = (59.02x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 3.95x10^{14}sej$$

G1.4 Seven Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 45.6 hours

$$Raw\ Units = (7)(45.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 361.97x10^{3}g$

$$Solar\ EMERGY = (361.97x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 2.43\ x10^{15}sej$$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 45.6 hours

$$Raw\ Units = (45.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 51.71x10^{3}g$

$$Solar\ EMERGY = (51.71x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 3.46x10^{14}sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 45.6

Salary = $ 37.45

$$Raw\ Units = (\frac{\$37.45}{hour})\ (45.6\ \text{hours})$$

=1,707.72$

$$Solar\ EMERGY = (1{,}707.72\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$= 3.42\ x10^{15} se\ j$

S1.2 Seven Laborers

Labor Hours = 45.6

Salary = \$ 35.45

$$Raw\ Units = (7)(\frac{\$\ 35.45}{hour})\ (45.6\ \text{hours})$$

=11,315.64\$

$$Solar\ EMERGY = (11{,}315.64\$)(2.00\ x10^{12}\ \frac{sej}{\$})$$

$=2.26\ x10^{16} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 45.6

Salary = \$ 47.50

$$Raw\ Units = (4)(\frac{\$47.50}{hour})\ (45.6\text{hours})$$

=8,664\$

$$Solar\ EMERGY = (8{,}664\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$= 1.73 x10^{16} se\ j$

S1.4 Eight Truck Drivers

Labor Hours = 45.6

Salary = \$ 47.50

$$Raw\ Units = (8)(\frac{\$\ 36.60}{hour})\ (45.6\ \text{hours})$$

=13,351.68$

$Solar\ EMERGY = (13{,}351.68\$)(2.00\ x10^{12}\frac{sej}{\$})$

=$2.67\ x10^{16} se\ j$

Fog Seal Shoulders

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$Quantity = (28\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$

$= 16.43x10^{3}SY$

$Mass = (16.43\ x10^{3}SY)(0.2\frac{gallon}{SY})$

$= 3{,}286\ gallons$

Rate $= (16.43x10^{3}SY)(\frac{1\ day}{5{,}000\ SY})$

$= 3.3\ days\left(8\frac{hrs}{day}\right)$

$= 26.4\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity = $6.6x10^{4}\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$Raw\ Units = (8.0\ \frac{gal}{hour})(26.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$

$=31.58x10^9 J$

$Solar\ EMERGY = (31.58\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$

$=\ 2.08x10^{15}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 26.4 hours

$Raw\ Units = (26.4\ hours)\left(\frac{1}{10,000\ hours}\right)(35,000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 41.91x10^3 g$

$Solar\ EMERGY = (41.91x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 2.81\ x10^{14} se\ j$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 26.4

Salary = $ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (26.4 hours)

=1,254$

$$Solar\ EMERGY = (1{,}254\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$$= 2.51\ x10^{15} se\ j$$

S1.2 One Truck Driver

Labor Hours = 26.4

Salary = $ 36.60

$$Raw\ Units = (\frac{\$\ 36.60}{hour})\ (26.4\ \text{hours})$$

=966.24$

$$Solar\ EMERGY = (966.24\$)(2.00\ x10^{12}\ \frac{sej}{\$})$$

$$=1.93\ x10^{15} se\ j$$

Prime Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28{,}160\ SY$$

$$Mass = (28{,}160\ SY)(0.35\frac{gallon}{SY})$$

$$= 9{,}856\ gallons$$

Rate $= (28{,}160\ SY)(\frac{1\ day}{5{,}000\ SY})$

$= 5.6\ days\left(8\frac{hrs}{day}\right)$

$= 44.8\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(44.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$=53.59x10^9 J$$

$$Solar\ EMERGY = (53.59\ x10^9 J)(6.6x10^4\frac{sej}{J})$$

$$=\ 3.54x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 44.8 hours

$$Raw\ Units = (44.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 71.12x10^3 g$$

$Solar\ EMERGY = (71.12x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 4.77x10^{14}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 44.8

Salary = $ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (44.8 hours)

=2,128$

$Solar\ EMERGY = (2{,}128\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 4.26\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 44.8

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (44.8 hours)

=1,639.68$

$Solar\ EMERGY = (1{,}639.68\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=3.28\ x10^{15} se\ j$

Tack Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28{,}160\ SY$$

$$Mass = (28{,}160\ SY)(0.06\frac{gallon}{SY})$$

$$= 1{,}689.6\ gallons$$

Rate $= (28{,}160\ SY)(\frac{1\ day}{5{,}000\ SY})$

$$= 5.6\ days\left(8\frac{hrs}{day}\right)$$

$$= 44.8\ hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(44.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$=53.59x10^9 J$$

$$Solar\ EMERGY = (53.59\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$= 3.54x10^{15}\ sej$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 44.8 hours

$Raw\ Units = (44.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 71.12x10^{3}g$

$Solar\ EMERGY = (71.12x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 4.77x10^{14}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 44.8

Salary = $ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (44.8 hours)

=2,128$

$Solar\ EMERGY = (2{,}128\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 4.26\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 44.8

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (44.8 hours)

=1,639.68$

$Solar\ EMERGY = (1{,}639.68\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=3.28\ x10^{15} se\ j$

Table IH-21: Use Phase - G
Use Phase at Year-23

		Phase-G Use Environmental Value Engineering EMERGY Analysis Input Table		
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$9.55\ x10^{8}J$		$6.36\ x10^{14}\ sej$
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$9.55\ x10^{8}J$	$6.66\ x10^{5}$	$6.36\ x10^{14}\ sej$
E-6	Materials	N/A		
F	FUEL ENERGY	$1.83\ x10^{12}J$		$1.21\ x10^{17}sej$
F-1	Equipment	$1.83\ x10^{12}J$	$6.6\ x10^{4}$	$1.21\ x10^{17}sej$
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$2.09\ x10^{6}g$		$1.40\ x10^{16}$sej
G-1	Equipment	$2.09\ x10^{6}g$	$6.7\ x10^{9}$	$1.40\ x10^{16}$sej
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	99,924.52$		$2.00\ x10^{17}sej$
S-1	Labor	99,924.52$	$2.00\ x10^{12}$	$2.00\ x10^{17}sej$
S-2	Materials	N/A		

Table IH-21: Use Phase - G
Use Phase at Year-23

Mill and replace 1.5 inches of surface course, including shoulders

Milling

Crew B-71

1-Outside labor foreman \$ 37.45

3-Laborers \$ 35.45

3-Equipment Operators \$ 47.50

9-Truck Driver \$ 36.60

Equipment

1-Cold Planer (86,360 pounds)

1-Road Sweeper (4,200 pounds)

1-Wheel Loader (24,251 pounds)

1-Water Truck (25,000 pounds)

8-Dump Trucks (25,000 pounds)

Milling duration based on 6,000 SY/day.

$$Quantity = (76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 44.59\ x10^3 SY$$

$$Mass = (44.59\ x10^3 SY)(168\frac{lb}{SY})$$

$$= (7.49\ x10^6 Lbs.)(\frac{1\ Ton}{2{,}000\ Lbs.})$$

$$= 3.75\ x10^3 Tons$$

Milling Duration = $(44.59\ x10^3 SY)(\frac{1\ day}{6{,}000\ SY})$

$$= 7.4\ days$$

$$= 59.2 \text{ hours}$$

Hauling Duration = $3.75\ x10^3 Tons\ (\frac{1\ truck}{16}tons)$

$= say\ 235\ trips$

$$= \frac{235\ trips}{7.4\ days}$$

$$= \frac{32\ trips}{day}$$

Each dump truck had a capacity of ~ 16 tons, so hauling duration and frequency was:

Haul distance was 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 8 trucks.

Environment

E5. Water

E.5.1 Water Transformity = $6.66\ x10^5\ \frac{sej}{J}$

1,000 gal/day (7.4 days) = 7,400 gallons

$$Raw\ Units = (7{,}400\ gal)\left(3.7854\frac{l}{gal}\right)\left(\frac{1{,}000\ g}{l}\right)\left(4.94\frac{J}{g}\right)^1$$

$= 138.38x10^6 J$

$$Solar\ EMERGY = (138.38x10^6 J)(6.66x10^4\frac{sej}{J})$$

$$= 9.22x10^{12}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4\frac{sej}{J}$

F1. Equipment

F1.1 One Cold Planer

Fuel consumption = 25 gal/hour

Use = $59.2\ hour$

$$Raw\ Units = (25\ \frac{gal}{hour})(59.2\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 221.3\ x10^9 J$

$$Solar\ EMERGY = (221.3\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ 1.46x10^{16}\ sej$$

F1.2 One Road Sweeper

Fuel consumption = 1.5 gal/hour

Use = 59.2 $hour$

$$Raw\ Units = (1.5\ \frac{gal}{hour})(59.2\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 13.28\ x10^9 J$

$$Solar\ EMERGY = (13.28\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ 8.76x10^{14}\ sej$$

F1.3 One Wheel Loader

Fuel consumption = 3.5 gal/hour

Use = 59.2 $hour$

$$Raw\ Units = (3.5\ \frac{gal}{hour})(59.2\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 30.98\ x10^9 J$

$$Solar\ EMERGY = (30.98\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ 2.04x10^{15}\ sej$$

F1.4 One Water Truck

Fuel consumption = 8 gal/hour

Use = 59.2 $hour$

$$Raw\ Units = (8\ \frac{gal}{hour})(59.2\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 70.81\ x10^9 J$

$Solar\ EMERGY = (70.81\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 4.67x10^{15}\ sej$

F1.4 Eight Dump Trucks

Fuel consumption = 8 gal/hour

Use = 59.2 $hour$

$$Raw\ Units = (8)(8\ \frac{gal}{hour})(59.2\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$= 566.62\ x10^9 J$

$Solar\ EMERGY = (566.62\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 3.74x10^{16}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Cold Planer

Weight = 86,360 LB

Useful Life = 10,000 hours

Use =59.2 hour

$$Raw\ Units = (59.2\ hour)\left(\frac{1}{10{,}000\ hours}\right)(86{,}360\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 231.90x10^3 g$

$Solar\ EMERGY = (231.90x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 1.55\ x10^{15} sej$

G1.2 One Road Sweeper

Weight = 4,200 LB

Useful Life = 10,000 hours

Use =59.2 hour

$$Raw\ Units = (59.2\ hour)\left(\frac{1}{10{,}000\ hours}\right)(4{,}200\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 11.28x10^{3}g$$

$$Solar\ EMERGY = (11.28x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 7.56\ x10^{13}sej$$

G1.3 One Wheel Loader

Weight = 24,251 LB

Useful Life = 10,000 hours

Use =59.2 hour

$$Raw\ Units = (59.2\ hour)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 65.12x10^{3}g$$

$$Solar\ EMERGY = (65.12x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 4.36\ x10^{14}sej$$

G1.4 One Water Truck

Weight = 25,000 LB

Useful Life = 10,000 hours

Use =59.2 hour

$$Raw\ Units = (59.2\ hour)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 67.13x10^{3}g$$

$$Solar\ EMERGY = (67.13x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 4.50x10^{14}$$

G1.5 Eight Dump Trucks

Weight = 25,000 LB

Useful Life = 10,000 hours

Use =59.2 hour

$$Raw\ Units = (8)(59.2\ hour)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 537.06x10^{3}g$

$$Solar\ EMERGY = (537.06x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 3.60\ x10^{15}sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One outside labor foreman

Labor Hours = 59.2

Salary = \$ 37.45

$$Raw\ Units = (\frac{\$\ 37.45}{hour})\ (59.2\ \text{hour})$$

=2,217.04\$

$$Solar\ EMERGY = (2{,}217.04\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

$= 4.43\ x10^{15}se\ j$

S1.2 Three labors

Labor Hours = 59.2

Salary = \$ 35.45

$Raw\ Units = (3)(\frac{\$\ 35.45}{hour})$ (59.2 hours)

=6,295.92$

$Solar\ EMERGY = (6{,}295.92\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.26\ x10^{16} se\ j$

S1.3 Three equipment operators

Labor Hours = 59.2

Salary = $ 47.50

$Raw\ Units = (3)(\frac{\$\ 47.50}{hour})$ (59.2 hours)

=8,436$

$Solar\ EMERGY = (8{,}436\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.69\ x10^{16} se\ j$

S1.4 Nine Truck Drivers

Labor Hours = 59.2

Salary = $ 36.60

$Raw\ Units = (9)(\frac{\$\ 36.60}{hour})$ (59.2 hours)

=19,500.68$

$Solar\ EMERGY = (19{,}500.68\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

=$3.90\ x10^{16} se\ j$

Place 1.5 Inches of Type S9.5C

Crew type is B-25B Modified

1-Labor Foreman $ 37.45

7-Laborers $ 35.45 per hour

4-Equipment Operators $ 47.50 per hour

8-Truck Drivers $ 36.60

Equipment type

1-Paver (39,044 pounds)

2-Tandem asphalt Rollers (23,525 pounds)

1-Asphalt wheel roller (28,535 pounds)

7-Dump trucks (25,000 pounds)

1-Water Truck (25,000 pounds)

$$Quantity = (76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 44.59\ x10^3 SY$$

$$Mass = (44.59\ x10^3 SY)(168\frac{lb}{SY})$$

$$= (7.49\ x10^6 Lbs.)(\frac{1\ Ton}{2{,}000\ Lbs.})$$

$$= 3.75\ x10^3 Tons$$

Rate $= (44.59\ x10^3 SY)(\frac{1\ day}{4{,}900\ SY})$

$$= 9.1\ days\left(8\frac{hrs}{day}\right)$$

$$= 72.8\ hours$$

Hauling Duration $= 3.75\ x10^3 Tons\ (\frac{1\ truck}{16}tons)$

$$= say\ 235\ trips$$

$$= \frac{235\ trips}{9.1\ days}$$

$$= \frac{26\ trips}{day}$$

Each dump truck had a capacity of ~ 16 tons, so hauling duration and frequency was:

Haul distance was 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 7 trucks.

Environment

E5. Water

E.5 1,600 gal/day per roller

Volume= $(3)(9.1\ days)(1{,}600\ \frac{gal}{day})$

$$= 43{,}680\ gallons$$

$$Raw\ Units = (43{,}680\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$$

$$= 816.81\ x10^6 J$$

$$Solar\ EMERGY = (816.81\ x10^6 J)(6.66x10^5\ \frac{sej}{J})$$

$$= \ 5.40x10^{14}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Paver (39,044 Lbs.)

Fuel consumption = 3.0 gal/hour

$$Raw\ Units = (3.0\ \frac{gal}{hour})(72.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^{1}$$

$$=32.66x10^9 J$$

$$Solar\ EMERGY = (32.66\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 2.16x10^{15}\ sej$$

F1.2 Two Tandem Asphalt Rollers (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = (2)(2.5\ \frac{gal}{hour})(72.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$=54.43x10^9 J$$

$$Solar\ EMERGY = (54.43\ x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 3.59x10^{15}\ sej$$

F1.3 Asphalt wheel roller (28,535 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = \ (3.5\ \frac{gal}{hour})(72.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 38.10\ x10^9 J$$

$$Solar\ EMERGY = (38.10x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 2.51x10^{15}\ sej$$

F1.4 Seven Dump Trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (7)(8\ \frac{gal}{hour})(72.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 609.58\ x10^9 J$$

$$Solar\ EMERGY = (609.58x10^9 J)(6.6x10^4 \frac{sej}{J})$$

$$= \ 4.02x10^{16}\ sej$$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(72.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$$= 87.08\ x10^9 J$$

$$Solar\ EMERGY\ = (87.08\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 5.75x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Paver

Weight = 39,044 Lbs.

Useful Life = 10,000 hours

Use = 72.8 hours

$$Raw\ Units\ = (72.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(39{,}044\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 128.93x10^3 g$$

$$Solar\ EMERGY\ = (128.93x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 8.64\ x10^{14} sej$$

G1.2 Two Tandem Asphalt Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 72.8 hours

$$Raw\ Units\ = (2)(72.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 155.37x10^3 g$$

$$Solar\ EMERGY\ = (155.37x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.04\ x10^{15} sej$$

G1.3 One Asphalt Wheel Roller

Weight = 28,535 Lbs.

Useful Life = 10,000 hours

Use = 72.8 hours

$$Raw\ Units = (72.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(28{,}535\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 94.23x10^3 g$

$$Solar\ EMERGY = (94.23x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 6.31x10^{14} sej$

G1.4 Seven Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (7)(72.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 577.89x10^3 g$

$$Solar\ EMERGY = (577.89x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 3.87\ x10^{15} sej$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 72.8 hours

$$Raw\ Units = (72.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 82.56x10^3 g$

$$Solar\ EMERGY = (82.56x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 5.53x10^{14} sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 72.8

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (72.8 hours)

=2,726.36$

$Solar\ EMERGY = (2{,}726.36\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

= 5.45 $x10^{15} se\ j$

S1.2 Seven Laborers

Labor Hours = 72.8

Salary = $ 35.45

$Raw\ Units = (7)(\frac{\$\ 35.45}{hour})$ (72.8 hours)

=18,065.32$

$Solar\ EMERGY = (18{,}065.32\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

=3.61 $x10^{16} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 72.8

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$47.50}{hour})$ (72.8 hours)

=13,832$

$Solar\ EMERGY = (13{,}832\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

$= 2.77\ x10^{16} se\ j$

S1.4 Eight Truck Drivers

Labor Hours = 72.8

Salary = $ 47.50

$Raw\ Units = (8)(\frac{\$\ 36.60}{hour})\ (72.8\ \text{hours})$

=21,315.84$

$Solar\ EMERGY = (21{,}315.84\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=4.26\ x10^{16} se\ j$

Prime Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28{,}160\ SY$$

$$Mass = (28{,}160\ SY)(0.35\frac{gallon}{SY})$$

$= 9{,}856\ gallons$

Rate $= (28{,}160\ SY)(\frac{1\ day}{5{,}000\ SY})$

$= 5.6\ days\left(8\frac{hrs}{day}\right)$

$= 44.8\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\,\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(44.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\,\frac{J}{barrel}\right)^1$$

$$=53.59x10^9 J$$

$$Solar\ EMERGY = (53.59\ x10^9 J)(6.6x10^4\,\frac{sej}{J})$$

$$=\ 3.54x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 44.8 hours

$Raw\ Units = (44.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 71.12x10^{3}g$

$Solar\ EMERGY = (71.12x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$

$= 4.77x10^{14}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 44.8

Salary = $ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (44.8 hours)

=2,128$

$Solar\ EMERGY = (2{,}128\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 4.26\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 44.8

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (44.8 hours)

=1,639.68$

$Solar\ EMERGY = (1{,}639.68\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=3.28\ x10^{15} se\ j$

Tack Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28{,}160\ SY$$

$$Mass = (28{,}160\ SY)(0.06\frac{gallon}{SY})$$

$$= 1{,}689.6\ gallons$$

Rate $= (28{,}160\ SY)(\frac{1\ day}{5{,}000\ SY})$

$$= 5.6\ days\left(8\frac{hrs}{day}\right)$$

$$= 44.8\ hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(44.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$=53.59x10^9 J$$

$$Solar\ EMERGY = (53.59\ x10^{9} J)(6.6x10^{4}\ \frac{sej}{J})$$

$$= 3.54x10^{15}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 44.8 hours

$$Raw\ Units = (44.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 71.12x10^{3} g$$

$$Solar\ EMERGY = (71.12x10^{3} g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 4.77x10^{14}\ sej$$

Services

Service/Labor Transformity = $2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 44.8

Salary = $ 47.50

$$Raw\ Units = (\frac{\$47.50}{hour})\ (44.8\ \text{hours})$$

=2,128$

$$Solar\ EMERGY = (2{,}128\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$$= 4.26\ x10^{15} se\ j$$

S1.2 One Truck Driver

Labor Hours = 44.8

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (44.8 hours)

=1,639.68$

$Solar\ EMERGY = (1{,}639.68\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$3.28\ x10^{15} se\ j$

Table IH-22: Use Phase - G
Use Phase at Year-34

		Phase-G Use Environmental Value Engineering EMERGY Analysis Input Table		
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	$2.09\ x10^{9} J$		$1.39\ x10^{15}$ sej
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	$2.09\ x10^{9} J$	$6.66\ x10^{5}$	$1.39\ x10^{15}$ sej
E-6	Materials	N/A		
F	FUEL ENERGY	$3.92\ x10^{12}$ J		$2.59\ x10^{17}$ sej
F-1	Equipment	$3.92\ x10^{12}$ J	$6.6\ x10^{4}$	$2.59\ x10^{17}$ sej
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	$4.59\ x10^{6} g$		$3.08\ x10^{16}$ sej
G-1	Equipment	$4.59\ x10^{6}$ g	$6.7\ x10^{9}$	$3.08\ x10^{16}$ sej
G-2	Facilities			
G-3	Goods			
G-4	Tools			
S	SERVICES	224,774.48$		$4.50\ x10^{17} sej$
S-1	Labor	224,774.48$	$2.00\ x10^{12}$	$4.50\ x10^{17} sej$
S-2	Materials	N/A		

Table IH-22: Use Phase - G
Use Phase at Year-34

Mill 3.0 inches of surface course, replace milling with intermediate course and 2 lifts of surface course to include shoulders.

Milling

Crew B-71

1-Outside labor foreman \$ 37.45

3-Laborers \$ 35.45

3-Equipment Operators \$ 47.50

17-Truck Drivers \$ 36.60

Equipment

1-Cold Planer (86,360 pounds)

1-Road Sweeper (4,200 pounds)

1-Wheel Loader (24,251 pounds)

1-Water Truck (25,000 pounds)

16-Dump Trucks (25,000 pounds)

Milling duration based on 6,000 SY/day.

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28.16\ x10^3 SY$$

$$Mass = (28.16\ x10^3 SY)(342\frac{lb}{SY})$$

$$= (9.63\ x10^6 Lbs.)(\frac{1\ Ton}{2{,}000\ Lbs.})$$

$$= 4{,}815\ Tons$$

Milling Duration = $(28.16\ x10^3 SY)(\frac{1\ day}{6{,}000\ SY})$

$$= 4.7\ days$$

= 37.6 hours

Hauling Duration = $4{,}815\ Tons\ (\frac{1\ truck}{16}tons)$

$$= say\ 301\ trips$$

$$= \frac{301\ trips}{4.7\ days}$$

$$= \frac{64\ trips}{day}$$

Each dump truck has a capacity of ~ 16 tons, so hauling duration and frequency is:

Haul distance is 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 16 trucks.

Environment

E5. Water

E.5.1 Water Transformity = $6.66\ x10^5\ \frac{sej}{J}$

1,000 gal/day (4.7 days) = 4,700 gallons

$$Raw\ Units = (4{,}700\ gal)\left(3.7854\frac{l}{gal}\right)\left(\frac{1{,}000\ g}{l}\right)\left(4.94\frac{J}{g}\right)^1$$

$$= 87.89x10^6 J$$

$$Solar\ EMERGY = (87.89x10^6 J)(6.66x10^5\frac{sej}{J})$$

$$= \ 5.85x10^{13}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4\frac{sej}{J}$

F1. Equipment

F1.1 One Cold Planer

Fuel consumption = 25 gal/hour

Use = $37.6\ hour$

$$Raw\ Units = (25\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 140.55\ x10^9 J$

$$Solar\ EMERGY = (140.55\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 9.28x10^{15}\ sej$

F1.2 One Road Sweeper

Fuel consumption = 1.5 gal/hour

Use = 37.6 $hour$

$$Raw\ Units = (1.5\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 8.43\ x10^9 J$

$$Solar\ EMERGY = (8.43\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 5.56x10^{14}\ sej$

F1.3 One Wheel Loader

Fuel consumption = 3.5 gal/hour

Use = 37.6 $hour$

$$Raw\ Units = (3.5\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 19.68\ x10^9 J$

$$Solar\ EMERGY = (19.68\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$= \ 1.30x10^{15}\ sej$

F1.4 One Water Truck

Fuel consumption = 8 gal/hour

Use = 37.6 $hour$

$$Raw\ Units = (8\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$= 44.98\ x10^9 J$

$Solar\ EMERGY = (44.98\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 2.97x10^{15}\ sej$

F1.5 Sixteen Dump Trucks

Fuel consumption = 8 gal/hour

Use = $37.6\ hour$

$$Raw\ Units = (16)(8\ \frac{gal}{hour})(37.6\ hour)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9 \frac{J}{barrel}\right)^1$$

$= 719.63\ x10^9 J$

$Solar\ EMERGY = (719.63\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= \ 4.75x10^{16}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 One Cold Planer

Weight = 86,360 LB

Useful Life = 10,000 hours

Use =37.6 hour

$$Raw\ Units = (37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(86{,}360\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 147.29x10^3 g$

$Solar\ EMERGY = (147.29x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 9.87\ x10^{14} sej$

G1.2 One Road Sweeper

Weight = 4,200 LB

Useful Life = 10,000 hours

Use =37.6 hour

$$Raw\ Units = (37.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(4{,}200\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 7.16x10^{3}g$$

$$Solar\ EMERGY = (7.16x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 4.80\ x10^{13}sej$$

G1.3 One Wheel Loader

Weight = 24,251 LB

Useful Life = 10,000 hours

Use =37.6 hour

$$Raw\ Units = (37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(24{,}251\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 41.36x10^{3}g$$

$$Solar\ EMERGY = (41.36x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 2.77\ x10^{14}sej$$

G1.4 One Water Truck

Weight = 25,000 LB

Useful Life = 10,000 hours

Use =37.6 hour

$$Raw\ Units = (37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 42.64x10^{3}g$$

$$Solar\ EMERGY = (42.64x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 2.86x10^{14}$$

G1.5 Sixteen Dump Trucks

Weight = 25,000 LB

Useful Life = 10,000 hours

Use =37.6 hour

$$Raw\ Units = (16)(37.6\ hour)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$= 682.21x10^{3}g$

$$Solar\ EMERGY = (682.21x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$= 4.57\ x10^{15}sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One outside labor foreman

Labor Hours = 37.6

Salary = \$ 37.45

$$Raw\ Units = (\frac{\$\ 37.45}{hour})\ (37.6\ \text{hour})$$

=1,408.12\$

$$Solar\ EMERGY = (1{,}408.12\$)\ (2.00\ x10^{12}\frac{sej}{\$})$$

$= 2.82\ x10^{15}se\ j$

S1.2 Three labors

Labor Hours = 37.6

Salary = \$ 35.45

$Raw\ Units = (3)(\frac{\$\ 35.45}{hour})$ (37.6 hours)

=3,998.76$

$Solar\ EMERGY = (3{,}998.76\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

=$8.00\ x10^{15} se\ j$

S1.3 Three equipment operators

Labor Hours = 37.6

Salary = $ 47.50

$Raw\ Units = (3)(\frac{\$\ 47.50}{hour})$ (37.6 hours)

=5,358$

$Solar\ EMERGY = (5{,}358\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

=$1.07\ x10^{16} se\ j$

S1.4 Seventeen Truck Drivers

Labor Hours = 37.6

Salary = $ 36.60

$Raw\ Units = (17)(\frac{\$\ 36.60}{hour})$ (37.6 hours)

=23,394.72$

$Solar\ EMERGY = (23{,}394.72\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$

=$4.68\ x10^{16} se\ j$

Material: Asphalt Concrete

Place 3 inches of Type I19.OC in one layer at a rate of 342 lb/SY

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)(342\frac{lb}{SY})$$

$$= 9.63\ x10^{6} lbs.\left(\frac{1\ Ton}{2{,}000\ lbs.}\right)$$

$$= 4{,}815\ Tons$$

Rate $= (28{,}160\ SY)(\frac{1\ day}{4{,}520\ SY})$

$$= 6.2\ days\left(8\frac{hrs}{day}\right)$$

$$= 49.6\ hours$$

Hauling Duration $= 4{,}815\ Tons\ (\frac{1\ truck}{16}tons)$

$$= say\ 301\ trips$$

$$= \frac{301\ trips}{6.2\ days}$$

$$= \frac{49\ trips}{day}$$

Each dump truck had a capacity of ~ 16 tons, so hauling duration and frequency was:

Haul distance was 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 13 trucks.

Crew type is B-25 Modified

1-Labor Foreman $ 37.45

7-Laborers $ 35.45 per hour

3-Equipment Operators $ 47.50 per hour

14-Truck Drivers $ 36.60

Equipment type

1-Paver (39,044 pounds)

1-Tandem asphalt roller (23,525 pounds)

1-Asphalt wheel roller (28,535 pounds)

13-Dump Trucks (25,000 pounds)

1-Water Truck (25,000 pounds)

Environment

E5. Water

E.5 1,600 gal/day per roller

Volume= $(2)(6.2\ days)(1{,}600\ \frac{gal}{day})$

$= 19{,}840\ gallons$

$Raw\ Units = (19{,}840\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$

$= 371\ x10^{6} J$

$Solar\ EMERGY = (371\ x10^{6} J)(6.66x10^{5}\ \frac{sej}{J})$

$=\ 2.47x10^{14}\ sej$

Fuel Energy

Petroleum Transformity = $6.6x10^{4}\ \frac{sej}{J}$

F1.1 Equipment

F1.1 One Paver (39,044 Lbs.)

Fuel consumption = 3.0 gal/hour

$Raw\ Units = (3.0\ \frac{gal}{hour})(49.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\ \frac{J}{barrel}\right)^{1}$

$=22.25x10^{9} J$

$Solar\ EMERGY = (22.25\ x10^{9} J)(6.6x10^{4}\ \frac{sej}{J})$

$=\ 1.47x10^{15}\ sej$

F1.2 One Tandem Asphalt Roller (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$Raw\ Units = (2.5\ \frac{gal}{hour})(49.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$

$=18.54x10^9 J$

$Solar\ EMERGY = (18.54\ x10^9 J)(6.6x10^4\frac{sej}{J})$

$=\ \ 1.22x10^{15}\ sej$

F1.3 One Asphalt wheel roller (28,535 Lbs.)

Fuel consumption = 3.5 gal/hour

$Raw\ Units = \ (3.5\ \frac{gal}{hour})(49.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$

$= 25.96\ x10^9 J$

$Solar\ EMERGY = (25.96x10^9 J)(6.6x10^4\frac{sej}{J})$

$=\ \ 1.71x10^{15}\ sej$

F1.4 Thirteen Dump Trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$Raw\ Units = (13)(8\ \frac{gal}{hour})(49.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$

$= 771.3\ x10^9 J$

$Solar\ EMERGY = (771.3x10^9 J)(6.6x10^4\frac{sej}{J})$

$=\ \ 5.09x10^{16}\ sej$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$Raw\ Units = (8\ \frac{gal}{hour})(49.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$

$= 59.33\ x10^9 J$

$Solar\ EMERGY = (59.33\ x10^9 J)(6.6x10^4\frac{sej}{J})$

$=\ \ 3.92x10^{15}\ sej$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 One Paver

Weight = 39,044 Lbs.

Useful Life = 10,000 hours

Use = 49.6 hours

$$Raw\ Units = (49.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(39{,}044\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 87.84x10^{3}g$$

$$Solar\ EMERGY = (87.84x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 5.89\ x10^{14}sej$$

G1.2 One Tandem Asphalt Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 49.6 hours

$$Raw\ Units = (49.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 52.93x10^{3}g$$

$$Solar\ EMERGY = (52.93x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 3.55\ x10^{14}sej$$

G1.3 One Asphalt Wheel Roller

Weight = 28,535 Lbs.

Useful Life = 10,000 hours

Use = 49.6 hours

$$Raw\ Units = (49.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(28{,}535\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 64.2x10^3 g$

$$Solar\ EMERGY = (64.2x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 4.3\ x10^{14} sej$$

G1.4 Thirteen Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 49.6 hours

$$Raw\ Units = (13)(49.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 731.2x10^3 g$

$$Solar\ EMERGY = (731.2x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 4.9\ x10^{15} sej$$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 49.6 hours

$$Raw\ Units = (49.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 56.25x10^3 g$

$$Solar\ EMERGY = (56.25x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 3.77x10^{14} sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 49.6

Salary = \$ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (49.6 hours)

=1,857.52\$

$Solar\ EMERGY = (1{,}857.52\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

$= 3.72\ x10^{15} se\ j$

S1.2 Seven Laborers

Labor Hours = 49.6

Salary = \$ 35.45

$Raw\ Units = (7)(\frac{\$\ 35.45}{hour})$ (49.6 hours)

=12,308.24\$

$Solar\ EMERGY = (12{,}308.24\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=2.46\ x10^{16} se\ j$

S1.3 Three Equipment Operators

Labor Hours = 49.6

Salary = \$ 47.50

$Raw\ Units = (3)(\frac{\$47.50}{hour})$ (49.6 hours)

=7,068\$

$Solar\ EMERGY = (7{,}068\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

$= 1.41\ x10^{16} se\ j$

S1.4 Fourteen Truck Drivers

Labor Hours = 49.6

Salary = $ 47.50

$Raw\ Units = (14)(\frac{\$\ 36.60}{hour})$ (49.6 hours)

=25,415.04$

$Solar\ EMERGY = (25{,}415.04\$)(2.00\ x10^{12}\frac{sej}{\$})$

$=5.08\ x10^{16} se\ j$

Prime Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28{,}160\ SY$$

$$Mass = (28{,}160\ SY)(0.35\frac{gallon}{SY})$$

$$= 9{,}856\ gallons$$

Rate $= (28{,}160\ SY)(\frac{1\ day}{5{,}000\ SY})$

$= 5.6\ days\left(8\frac{hrs}{day}\right)$

$= 44.8\ hours$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(44.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$=53.59x10^9 J$

$$Solar\ EMERGY = (53.59\ x10^9 J)(6.6x10^4\frac{sej}{J})$$

$= \ 3.54x10^{15}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 44.8 hours

$$Raw\ Units = (44.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 71.12x10^3 g$

$Solar\ EMERGY = (71.12x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 4.77x10^{14}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\,\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 44.8

Salary = $ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (44.8 hours)

=2,128$

$Solar\ EMERGY = (2{,}128\$)\ (2.00\ x10^{12}\,\frac{sej}{\$})$

$= 4.26\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 44.8

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (44.8 hours)

=1,639.68$

$Solar\ EMERGY = (1{,}639.68\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=3.28\ x10^{15} se\ j$

Tack Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (48\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 28{,}160\ SY$$

$$Mass = (28{,}160\ SY)(0.06\frac{gallon}{SY})$$

$$= 1{,}689.6\ gallons$$

Rate $= (28{,}160\ SY)(\frac{1\ day}{5{,}000\ SY})$

$$= 5.6\ days\left(8\frac{hrs}{day}\right)$$

$$= 44.8\ hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(44.8\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$=53.59x10^9 J$$

$Solar\ EMERGY = (53.59\ x10^9 J)(6.6x10^4 \frac{sej}{J})$

$= 3.54x10^{15}\ sej$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 44.8 hours

$Raw\ Units = (44.8\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$

$= 71.12x10^3 g$

$Solar\ EMERGY = (71.12x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 4.77x10^{14}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12} \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 44.8

Salary = \$ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (44.8 hours)

=2,128\$

$Solar\ EMERGY = (2{,}128\$)\ (2.00\ x10^{12} \frac{sej}{\$})$

$= 4.26\ x10^{15} se\ j$

S1.2 One Truck Driver

Labor Hours = 44.8

Salary = $ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (44.8 hours)

=1,639.68$

$Solar\ EMERGY = (1{,}639.68\$)(2.00\ x10^{12}\,\frac{sej}{\$})$

$=3.28\ x10^{15} se\ j$

Material: Asphalt Concrete

Place in two layers; each at a rate of 168 lb/SY or 1.5 inches thick

$$Quantity = (2)(76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)(168\frac{lb}{SY})$$

$$= 14.98\ x10^{6} lbs.\left(\frac{1\ Ton}{2{,}000\ lbs.}\right)$$

$$= 7.49\ x10^{3} Tons$$

Rate $= (89.17\ x10^{3} SY)(\frac{1\ day}{4{,}900\ SY})$

$$= 18.2\ days\left(8\frac{hrs}{day}\right)$$

$$= 145.6\ hours$$

Hauling Duration $= 7.49\ x10^{3} Tons\ (\frac{1\ truck}{16} tons)$

$$= say\ 468\ trips$$

$$= \frac{468\ trips}{18.2\ days}$$

$$= \frac{26\ trips}{day}$$

Each dump truck had a capacity of ~ 16 tons, so hauling duration and frequency was:

Haul distance was 20 miles round trip at 2 hours per trip or 4 trips per day per truck; therefore use 7 trucks.

Crew type is B-25B Modified

1-Labor Foreman $ 37.45

7-Laborers $ 35.45 per hour

4-Equipment Operators $ 47.50 per hour

8-Truck Drivers $ 36.60

Equipment type

1-Paver (39,044 pounds)

2-Tandem asphalt Rollers (23,525 pounds)

1-Asphalt wheel roller (28,535 pounds)

7-Dump trucks (25,000 pounds)

1-Water Truck (25,000 pounds)

Environment

E5. Water

E.5 1,600 gal/day per roller

$$\text{Volume} = (3)(18.2\ days)(1{,}600\ \frac{gal}{day})$$

$$= 87{,}360\ gallons$$

$$Raw\ Units = (87{,}360\ gal)(3.7854\ \frac{l}{gal})\left(\frac{1{,}000\ g}{l}\right)\left(\frac{4.94\ J}{g}\right)^{1}$$

$$= 1.63\ x10^{9} J$$

$$Solar\ EMERGY = (1.63\ x10^{9} J)(6.66x10^{5}\ \frac{sej}{J})$$

$$= 1.09x10^{15}\ sej$$

Fuel Energy

Petroleum Transformity = $6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Paver (39,044 Lbs.)

Fuel consumption = 3.0 gal/hour

$$Raw\ Units = (3.0\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$=65.31x10^9 J$$

$$Solar\ EMERGY = (65.31\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 4.31x10^{15}\ sej$$

F1.2 Two Tandem Asphalt Rollers (23,525 Lbs.)

Fuel consumption = 2.5 gal/hour

$$Raw\ Units = (2)(2.5\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$=108.85x10^9 J$$

$$Solar\ EMERGY = (108.85\ x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 7.18x10^{15}\ sej$$

F1.3 One Asphalt wheel roller (28,535 Lbs.)

Fuel consumption = 3.5 gal/hour

$$Raw\ Units = (3.5\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 76.20\ x10^9 J$$

$$Solar\ EMERGY = (76.20x10^9 J)(6.6x10^4\ \frac{sej}{J})$$

$$=\ \ 5.03x10^{15}\ sej$$

F1.4 Seven Dump trucks (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (7)(8\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\ \frac{J}{barrel}\right)^1$$

$$= 1.22\ x10^{12} J$$

$$Solar\ EMERGY = (1.22x10^{12}J)(6.6x10^{4}\frac{sej}{J})$$

$$= 8.05x10^{16}\ sej$$

F1.5 One Water Truck (25,000 Lbs.)

Fuel consumption = 8 gal/hour

$$Raw\ Units = (8\ \frac{gal}{hour})(145.6\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^{9}\frac{J}{barrel}\right)^{1}$$

$$= 174.17\ x10^{9}J$$

$$Solar\ EMERGY = (174.17\ x10^{9}J)(6.6x10^{4}\frac{sej}{J})$$

$$= 1.15x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^{9}\ \frac{sej}{g}$

G1. Equipment

G1.1 One Paver

Weight = 39,044 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(39{,}044\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

$$= 257.86x10^{3}g$$

$$Solar\ EMERGY = (257.86x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.73\ x10^{15}sej$$

G1.2 Two Tandem Asphalt Roller

Weight = 23,525 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (2)(145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(23{,}525\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

= $310.74x10^{3}g$

$$Solar\ EMERGY = (310.74x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 2.08\ x10^{15}sej$$

G1.3 One Asphalt Wheel Roller

Weight = 28,535 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(28{,}535\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

= $188.46x10^{3}g$

$$Solar\ EMERGY = (188.46x10^{3}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 1.26x10^{15}sej$$

G1.4 Seven Dump Trucks

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$$Raw\ Units = (7)(145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$$

= $1.16x10^{6}g$

$$Solar\ EMERGY = (1.16x10^{6}g)(6.7\ x10^{9}\ \frac{sej}{g})$$

$$= 7.77\ x10^{15}sej$$

G1.5 One Water Truck

Weight = 25,000 Lbs.

Useful Life = 10,000 hours

Use = 145.6 hours

$Raw\ Units = (145.6\ hours)\left(\frac{1}{10{,}000\ hours}\right)(25{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^{1}$

$= 165.11x10^3 g$

$Solar\ EMERGY = (165.11x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$

$= 1.11x10^{15} sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12} \frac{sej}{\$}$

S1.1 One Labor Foreman

Labor Hours = 145.6

Salary = $ 37.45

$Raw\ Units = (\frac{\$37.45}{hour})$ (145.6 hours)

=5,452.72$

$Solar\ EMERGY = (5{,}452.72\$)\ (2.00\ x10^{12} \frac{sej}{\$})$

$= 1.09\ x10^{16} se\ j$

S1.2 Seven Laborers

Labor Hours = 145.6

Salary = $ 35.45

$Raw\ Units = (7)(\frac{\$\ 35.45}{hour})$ (145.6 hours)

=36,130.64$

$Solar\ EMERGY = (36{,}130.64\$)(2.00\ x10^{12} \frac{sej}{\$})$

$=7.23\ x10^{16} se\ j$

S1.3 Four Equipment Operators

Labor Hours = 145.6

Salary = $ 47.50

$Raw\ Units = (4)(\frac{\$47.50}{hour})$ (145.6 hours)

=27,664$

$Solar\ EMERGY = (27{,}664\$)\ (2.00\ x10^{12}\frac{sej}{\$})$

= 5.53 $x10^{16} se\ j$

S1.4 Eight Truck Drivers

Labor Hours = 145.6

Salary = $ 47.50

$Raw\ Units = (8)(\frac{\$\ 36.60}{hour})$ (145.6 hours)

=42,631.68$

$Solar\ EMERGY = (42{,}631.68\$)(2.00\ x10^{12}\frac{sej}{\$})$

=8.53 $x10^{16} se\ j$

Prime Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (2)(76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 89{,}173.3\ SY$$

$$Mass = (89{,}173.3\ SY)(0.35\frac{gallon}{SY})$$

$$= 31{,}210.7\ gallons$$

Rate $= (89{,}173.3\ SY)(\frac{1\ day}{5{,}000\ SY})$

$$= 17.8\ days\left(8\frac{hrs}{day}\right)$$

$$= 142.4\ hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4\,\frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(142.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\,\frac{J}{barrel}\right)^1$$

$$=170.34x10^9 J$$

$$Solar\ EMERGY = (170.34\ x10^9 J)(6.6x10^4\,\frac{sej}{J})$$

$$= 1.12x10^{16}\ sej$$

Goods

Machinery Transformity= $6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 142.4 hours

$$Raw\ Units = (142.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$= 226.07x10^3 g$

$$Solar\ EMERGY = (226.07x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$= 1.51x10^{15}\ sej$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\ \frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 142.4

Salary = $ 47.50

$$Raw\ Units = (\frac{\$47.50}{hour})\ (142.4\ \text{hours})$$

=6,764$

$$Solar\ EMERGY = (6{,}764\$)\ (2.00\ x10^{12}\ \frac{sej}{\$})$$

$= 1.35\ x10^{16} se\ j$

S1.2 One Truck Driver

Labor Hours = 142.4

Salary = $ 36.60

$$Raw\ Units = (\frac{\$\ 36.60}{hour})\ (142.4\ \text{hours})$$

=5,511.84$

$Solar\ EMERGY = (5{,}211.84\$)(2.00\ x10^{12}\ \frac{sej}{\$})$

$=1.04\ x10^{16} se\ j$

Tack Coat

Crew type is B-45

1-Equipment Operator $ 47.50

1-Truck Driver $ 36.60

Equipment type

1-Semi Tractor with Tanker (35,000 pounds)

$$Quantity = (2)(76\ ft)(5{,}280\ ft)\left(\frac{1\ SY}{9\ sf}\right)$$

$$= 89{,}173.3\ SY$$

$$Mass = (89{,}173.3\ SY)(0.06\frac{gallon}{SY})$$

$$= 5{,}350.4\ gallons$$

$$\text{Rate} = (89{,}173.3\ SY)(\frac{1\ day}{5{,}000\ SY})$$

$$= 17.8\ days\left(8\frac{hrs}{day}\right)$$

$$= 142.4\ hours$$

Environment

E5. Water

E.5 No water used in this application

Fuel Energy

Petroleum Transformity $= 6.6x10^4 \frac{sej}{J}$

F1.1 Equipment

F1.1 One Semi-Truck with Tanker (35,000 Lbs.)

Fuel consumption = 8.0 gal/hour

$$Raw\ Units = (8.0\ \frac{gal}{hour})(142.4\ hours)\left(\frac{barrel}{42\ gal}\right)\left(6.28x10^9\frac{J}{barrel}\right)^1$$

$$=170.34x10^9 J$$

$$Solar\ EMERGY = (170.34\ x10^9 J)(6.6x10^4\frac{sej}{J})$$

$$=\ 1.12x10^{16}\ sej$$

Goods

Machinery Transformity$= 6.7\ x10^9\ \frac{sej}{g}$

G1. Equipment

G1.1 Semi-Truck with Tanker

Weight = 35,000 Lbs.

Useful Life = 10,000 hours

Use = 142.4 hours

$$Raw\ Units = (142.4\ hours)\left(\frac{1}{10{,}000\ hours}\right)(35{,}000\ LB)\left(453.6\ \frac{g}{LB}\right)^1$$

$$= 226.07x10^3 g$$

$$Solar\ EMERGY = (226.07x10^3 g)(6.7\ x10^9\ \frac{sej}{g})$$

$$= 1.51x10^{15}\ sej$$

Services

Service/Labor Transformity $= 2.00\ x10^{12}\frac{sej}{\$}$

S1.1 One Equipment Operator

Labor Hours = 142.4

Salary = \$ 47.50

$Raw\ Units = (\frac{\$47.50}{hour})$ (142.4 hours)

=6,764\$

$Solar\ EMERGY = $ (6,764\$) (2.00 $x10^{12}\frac{sej}{\$}$)

= 1.35 $x10^{16} se\ j$

S1.2 One Truck Driver

Labor Hours = 142.4

Salary = \$ 36.60

$Raw\ Units = (\frac{\$\ 36.60}{hour})$ (142.4 hours)

=5,511.84\$

$Solar\ EMERGY = $ (5,211.84\$)(2.00 $x10^{12}\frac{sej}{\$}$)

=1.04 $x10^{16} se\ j$

Table IH-23: Demolition Phase H
Demolition

	Phase-H Demolition Environmental Value Engineering EMERGY Analysis Input Table			
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY associated with demolition were not calculated separately given the fact that the demolition occurred in the use phase.

Table IHR-23: Demolition Phase H
Demolition

The EMERGY associated with demolition ere not calculated separately given the fact that the demolition occurred in the use phase.

Table IH-24: Recycling Phase I
Recycling

Phase-I Natural Resource Recycling
Environmental Value Engineering EMERGY Analysis Input Table

Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

The EMERGY inputs for recycling were zero because the recyclable material was removed during the use phase.

Table IH-24: Recycling Phase I
Recycling

The EMERGY inputs for recycling were zero because the recyclable material was removed during the use phase.

Table IH-25: Disposal Phase J
Disposal

Phase-J Disposal Environmental Value Engineering EMERGY Analysis Input Table				
Source	Item	Raw Units (g, J, $)	Transformity (sej/unit)	Solar EMERGY (seJ)
E	ENVIRONMENT	N/A		
E-1	Atmosphere	N/A		
E-2	Ecol. Prod.	N/A		
E-3	Energy	N/A		
E-4	Land	N/A		
E-5	Water	N/A		
E-6	Materials	N/A		
F	FUEL ENERGY	N/A		
F-1	Equipment	N/A		
F-2	Facilities	N/A		
F-3	Materials	N/A		
G	GOODS	N/A		
G-1	Equipment	N/A		
G-2	Facilities	N/A		
G-3	Goods	N/A		
G-4	Tools	N/A		
S	SERVICES	N/A		
S-1	Labor	N/A		
S-2	Materials	N/A		

All EMERGY inputs equaled zero based upon no disposal for the high speed passenger rail and Interstate highway transportation alternatives.

Table IH-25 Disposal Phase-J
Disposal

All EMERGY inputs equaled zero based upon no disposal for the high speed passenger rail and Interstate highway transportation alternatives.

APPENDIX D: AGGREGATED EMERGY INPUT TABLES

Aggregated EMERGY Input Rail – Alternative 1(High-Speed Passenger Rail)

EVE Phase	EMERGY Input Source Data (sej)				Total Phase	
	Environment (E)	Fuel (F)	Goods (G)	Services (S)	EMERGY	ANOVA
A – C Transformity	$4.44\ x10^{19}$	$6.00\ x10^{18}$	$6.00\ x10^{18}$	$6.00\ x10^{18}$	$6.24\ x10^{19}$	1
D Design	0	0	0	0	0	1
E Comp. Prod.	$8.52\ x10^{20}$	$1.22\ x10^{20}$	$1.22\ x10^{20}$	$1.22\ x10^{20}$	$1.22\ x10^{21}$	1
F Construction	$1.06\ x10^{15}$	$9.50\ x10^{17}$	$3.13\ x10^{17}$	$4.97\ x10^{18}$	$6.23\ x10^{18}$	1
G Use	$1.66\ x10^{13}$	$3.33\ x10^{17}$	$2.26\ x10^{16}$	$9.25\ x10^{16}$	$4.48\ x10^{17}$	1
H Demolition	0	0	0	0	0	1
I Recycling	0	0	0	0	0	1
J Disposal	0	0	0	0	0	1
Total High-Speed Passenger Rail Transportation System EMERGY					$1.29\ x10^{21}$	1

.

Aggregated EMERGY Input Interstate – Alternative 2 (Interstate Passenger Car)

EVE Phase	EMERGY Input Source Data (sej) Environment (E)	Fuel (F)	Goods (G)	Services (S)	Total Phase EMERGY	ANOVA
A – C Transformity	$1.74\ x10^{20}$	$2.45\ x10^{19}$	$2.45\ x10^{19}$	$2.45\ x10^{19}$	$2.45\ x10^{20}$	2
D Design	0	0	0	0	0	2
E Comp. Prod.	0	0	0	0	0	2
F Construction	$4.01\ x10^{15}$	$1.09\ x10^{18}$	$1.23\ x10^{17}$	$1.73\ x10^{18}$	$2.94\ x10^{18}$	2
G Use	$2.43\ x10^{15}$	$8.11\ x10^{17}$	$5.43\ x10^{16}$	$7.83\ x10^{17}$	$1.65\ x10^{18}$	2
H Demolition	0	0	0	0	0	2
I Recycling	0	0	0	0	0	2
J Disposal	0	0	0	0	0	2
Total Interstate Passenger Car Transportation System EMERGY					$2.52\ x10^{20}$	2

APPENDIX E: COMPOSITE EMERGY VALUES BY GROUP

Composite Phased EMERGY Values for Environment (E)

EVE Phase	Total Source Phase EMERGY (sej) Alternative-1	Total Source Phase EMERGY (sej) Alternative-2
A - C Transformity	$4.44\ x10^{19}$	$1.74\ x10^{20}$
D Design	0	0
E Comp. Prod.	$8.52\ x10^{20}$	0
F Construction	$1.06\ x10^{15}$	$4.01\ x10^{15}$
G Use	$1.66\ x10^{13}$	$2.43\ x10^{15}$
H Demolition	0	0
I Recycling	0	0
J Disposal	0	0
Total	$8.96\ x\ 10^{20}$	$1.74\ x10^{20}$

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

Composite EMERGY Values for Fuel (F)

EVE Phase	Total Source Phase EMERGY (sej) Alternative-1	Total Source Phase EMERGY (sej) Alternative-2
A - C Transformity	$6.00\ x10^{18}$	$2.45\ x10^{19}$
D Design	0	0
E Comp. Prod.	$1.22\ x10^{20}$	0
F Construction	$9.50\ x10^{17}$	$1.09\ x10^{18}$
G Use	$3.33\ x10^{17}$	$8.11\ x10^{17}$
H Demolition	0	0
I Recycling	0	0
J Disposal	0	0
Total	$1.29\ x10^{20}$	$2.64\ x10^{19}$

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

Composite Phased EMERGY Values for Goods (G)

EVE Phase	Total Source Phase EMERGY (sej) Alternative-1	Total Source Phase EMERGY (sej) Alternative-2
A – C Transformity	$6.00\ x10^{18}$	$2.45\ x10^{19}$
D Design	0	0
E Comp. Prod.	$1.22\ x10^{20}$	0
F Construction	$3.13\ x10^{17}$	$1.23\ x10^{17}$
G Use	$2.26\ x10^{16}$	$5.43\ x10^{16}$
H Demolition	0	0
I Recycling	0	0
J Disposal	0	0
Total	$1.28\ x10^{20}$	$2.47\ x10^{19}$

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

Composite Phased EMERGY Values for Services (S)

EVE Phase	Total Source Phase EMERGY (sej) Alternative-1	Total Source Phase EMERGY (sej) Alternative-2
A - C Transformity	$6.00\ x10^{18}$	$2.45\ x10^{19}$
D Design	0	0
E Comp. Prod.	$1.22\ x10^{20}$	0
F Construction	$4.97\ x10^{18}$	$1.73\ x10^{18}$
G Use	$9.25\ x10^{16}$	$7.83\ x10^{17}$
H Demolition	0	0
I Recycling	0	0
J Disposal	0	0
Total	$1.33\ x10^{20}$	$2.70\ x10^{19}$

Alternative 1 (High-Speed Passenger Rail) - Alternative 2 (Interstate Passenger Car)

APPENDIX-F: TRANSFORMITIES

MATERIAL TRANSFORMITIES –Refer to notes 1 and 2 unless noted

Aluminum ingots (g)	1.60E10
Asphalt (J)	3.47E5
Asphalt concrete (g)	1.78E9
Coal (J)	3.98E4
Concrete (g)	9.99E8
Copper (g)	6.80E10
Electricity (J)	1.59E5
Glass (g)	8.40E8
Grain (J)	6.80E4
Iron (g)	1.80E9
Limestone (g)	8.14E9 (Refer to note 3)
Machinery (g)	6.70E9
Natural gas (J)	4.80E4
Nitrogen fertilizer (J)	1.69E6
Oil (J)	5.30E4
Paper (J)	2.15E5
Petroleum product (J)	6.60E4
Plastic (g)	3.80E8
Rubber (g)	4.30E9
Service, labor (US$)	2.00E12 (Refer to note 4)
Steel (g)	1.80E9
Stone, mined (g)	1.00E9
Stone, natural state (g)	8.50E8
Topsoil (J)	6.30E4
Topsoil (g)	1.71E9 (Refer to note 5)
Water, consumer (J)	6.66E5
Water, waste (J)	4.10E4
Wood (J)	3.49E4
Zinc Alloys (g)	6.80E10

Notes:

1. Transformity units are solar emjoules/Joule, solar Emjoules/gram or solar emjoules/US $.
2. Source: Dr. Howard T. Odum, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida.
3. Source: Stachetti, (n.d.)
4. Units in 1990 U. S. dollars.
5. Source: Atalah, Onsarigo & Roudebush 2012

Source. Modified from Roudebush (1996)

APPENDIX G: EQUIPMENT SCHEDULE

Item	Description	Weight Pounds	Fuel	Rate	Useful Life Hours/Miles	Data Source
1	30 ft. Utility Poles (Steel)	500	N/A	N/A	219,000	F-Q-W
2	Asphalt 5-Wheel Roller (Caterpillar PS150C)	28,535	3.5	gal/hr.	10,000	A-N-V
3	Ballast Regulator (Harsco BE-KR)	56,000	8	gal/hr.	20,800	K-P-W
4	Base Compactor/Roller (Caterpillar CS-433E)	14,875	3.5	gal/hr.	10,000	A-N-V
5	Brush Chipper - 12 inch 130 HP (Vermeer BC 1500)	6,907	7.0	gal/hr.	6,000	B-O-W
6	Bull Dozer (Caterpillar D8T)	87,733	11.7	gal/hr.	18,000	A-N-V
7	Bull Dozer 200 HP (Caterpillar D6T)	48,588	7.4	gal/hr.	14,000	A-N-V
8	Catenary System	250	N/A	N/A	219,000	F-Q-W
9	Chain saw 36 Inch (Stihl MS 880 R)	23	0.7	gal/hr.	400	C-P-X
10	Cold Planer (Caterpillar PM-201)	86,360	25.0	gal/hr.	10,000	A-N-V

Item	Description	Weight Pounds	Fuel	Rate	Useful Life Hours/Miles	Data Source
11	Dump Truck 16T (Caterpillar CT660)	25,000	8.0	gal/hr.	10,000/500,000	A-P-V
12	Flat Bed Work Truck (3 ton)	8,000	4	gal/hr.	7,500	F-P-W
13	Front-end Track Loader (Caterpillar 963D)	44,577	7.7	gal/hr.	10,000	A-N-V
14	Grader (Caterpillar 120M2)	39,892	5.0	gal/hr.	15,000	A-N-V
15	Harsco TRT 909 Train	2,872,000	300	gal/hr.	52,000	K-P-W
16	Herzog (GPS Rail Car)	74,000	N/A	N/A	31,200	J-Q-W
17	Hydraulic Crane	24,000	4	gal/hr.	15,000	F-P-W
18	Hydraulic Excavator (Caterpillar 324D L)	54,660	6.3	gal/hr.	10,000	A-N-V
19	Hydraulic Power Unit (Stanley GT23)	330	1.3	gal/hr.	3,840	E-Q-W
20	Locomotive (GATX GP 38-2)	250,000	150	gal/hr.	52,000	I-R-W
21	Loram HP Shoulder Ballast Cleaner	536,000	40	gal/hr.	52,000	M-P-W
22	Mobile Crane (Liebherr LTM 1095-5.1)	132,000	12	gal/hr.	20,800	L-P-W

Item	Description	Weight Pounds	Fuel	Rate	Useful Life Hours/Miles	Data Source
23	Orgo-Thermit Single Use Crucible (15-10-I140RE)	77	N/A	N/A	Each Weld	H-Q-Y
24	Orgo-Thermit Tool Kit (40-25-102)	155	N/A	N/A	1,920	H-Q-W
25	Oxygen/Acetylene Tanks	175	N/A	N/A	Daily	G-Q-W
26	Paver (Caterpillar AP555E)	39,044	3.0	gal/hr.	10,000	A-N-V
27	Rail Jack (Stanley TJ10)	44	N/A	N/A	5,760	E-Q-W
28	Rail Saw and Clamp Set (Stanley RS25100)	56	N/A	N/A	5,760	E-Q-W
29	Rail Train	1,940,000	300	gal/hr.	52,000	F-P-W
30	Reactor	240,000	N/A	N/A	350,400	F-Q-W
31	Road Reclaimer (Caterpillar RM500)	62,060	18	gal/hr.	18,000	A-N-W
32	Road Sweeper (Lay-Mor 400)	4,200	1.5	gal/hr.	10,000	D-P-W
33	S. P. Crane	10,000	2.5	gal/hr.	15,000	F-P-W
34	Semi-Tractor Trailer (Caterpillar CT660)	35,000	8.0	gal/hr.	10,000/500,000	A-P-V
35	Semi-Tractor with Tanker (Caterpillar CT660)	35,000	8.0	gal/hr.	10,000/500,000	A-P-V

Item	Description	Weight Pounds	Fuel	Rate	Useful Life Hours/Miles	Data Source
36	Tamper (Harsco 6700 PD)	70,000	10.5	gal/hr.	20,800	K-P-W
37	Tandem Asphalt Roller (Caterpillar CB54B)	23,525	2.5	gal/hr.	10,000	A-N-V
38	Track Undercutter (Harsco GO4S-III-C)	180,000	40	gal/hr.	52,000	K-P-W
39	Transformer (400 - 25 KV)	398,000	N/A	N/A	350,400	F-Q-W
40	Upright Rail Grinder (Stanley PG10)	26	N/A	N/A	5,760	E-Q-W
41	Vibratory Roller (Caterpillar CS78B	41,214	5.0	gal/hr.	10,000	A-N-V
42	Water Truck 5,000 gallons (Caterpillar CT660)	25,000	8.0	gal/hr.	10,000/500,000	A-P-V
41	Weld Shear (Stanley WS10)	100	N/A	N/A	5,760	E-Q-W
42	Wheel Loader/Backhoe (Caterpillar 430F)	24,251	3.5	gal/hr.	10,000	A-N-V
43	Work Truck (1 Ton Dual Axle)	8,000	2.5	gal/hr.	5760/200,000	F-P-W

Data Source
Weight
A-Caterpillar
B-Vermeer
C-Stihl
D-Lay-Mor
E-Stanley Railroad Products
F-Estimate
G-Praxair
H-Orgo-Thermit
I - GATX Locomotives
J - Herzog
K - Harsco
L-Liebherr
M-Loram
Fuel
N-Caterpillar Performance Handbook
O-Vermeer
P-Estimate
Q-N/A
R - GATX
S - Harsco
T-Loram
U-Liebherr
Useful Life
V-Calculation of Mac
W-Estimate
X-Useful Life and Fle›
Y-Orgo-Thermit