

Appendix A

These bar graph notes and equations are assembled, reformatted and annotated from the Endnotes in Odum (1987, pp. 80-81). It was admittedly a challenge to decipher the Endnotes. There was very little description, and there were several arithmetic errors. Of most importance for the study, it was here that I discovered the Specification Books calculation, which was omitted from Figure 6. I cannot know of course, but it may be that Odum omitted that value from the bar graph because he did not want to distract from the main information outputs, the maps and the 'shared original' map.

Highway Construction and Maintenance

Two bars are related to the construction and maintenance of the highway (Figure 7, Bars 2 and 5). They are therefore calculations that utilize the construction and maintenance emergy of 3.97 E22 sej/yr. Odum offered no derivation of this aggregated emergy input in Odum (1987) (it was taken directly from the student report referred to above (Lyu, 1986)), except to say that it was the product of the emergy of fuels, asphalt, cement, steel, and labor. It was apparently evaluated elsewhere and treated here as a given. The same is true for the aggregated emergy input for Highway Use, 15.1 E22 sej/J, applied below. Again, both values are displayed in the top-right corner of Figure 7.

Production, Highways

For Texas highways in 1986, 3.97 E22 solar emjoules per year are required in the construction processes that produced and maintained the highway system. The second bar (Figure 7, Production, Highways) is the energy used in this construction and maintenance process, which was 9.07 E16 J/yr.

Solar transformity of highway construction and replacement:

$$(3.97 \text{ E22 sej/yr}) / (9.07 \text{ E16 J/yr}) = \underline{4.38 \text{ E5 sej/J}} \text{ (corrected from } 4.38 \text{ E6 sej/J in the Endnotes, (1987, p. 81))}$$

Specification Books (Transformity of Duplicates)

This item is referred to as highway construction specifications. These are detailed construction procedures that have been 'extracted' (or 'abstracted') from successful highway construction, *copied*, and *dispersed* to the many work sites. Odum estimates that in printed form this is about 1000 kilograms of books, updated each year, the energy content of which is therefore:

$$(1 \text{ E6 g/yr}) (4 \text{ kilocalories per g}) (4186 \text{ J/kilocalorie}) = \underline{1.67 \text{ E10 J/yr}}$$

The same aggregated emergy flow is used for this calculation, that is, the 3.97 E22 solar emjoules per year required in the production process that maintained the highway system.

Solar transformity of the highway specification books:

$$(3.97 \text{ E22 sej/yr}) / (1.67 \text{ E10 J/yr}) = \underline{2.37 \text{ E12 sej/J}}$$

Highway Use

These next three bars are related to the use of the highway (Figure 7, Bars 3, 4, and 6). They are therefore calculations that utilize the Highway Use Emergy of 15.1 E22 sej/yr. Once again, this second aggregated value is taken directly from the student report referred to above (Lyu, 1986).

Control System, Intersections

Odum did not discuss this bar. My interpretation is that this is the material component of 'highway use'. In other words, a control system to guide drivers through a network of roads and intersections. It is the material system from which the information for maps is extracted. There is no calculation shown, but there is a transformity on Figure 6. I have used the 'Highway Use Emergy' to back-calculate the available energy input (3.45 E16 J), and include it in Figure 7.

$$(15.1 \text{ E22 sej/yr}) / (4.38 \text{ E6 sej/J}) = 3.45 \text{ E16 J/yr}$$

Abstracted Information, Copies (Map Copies) (Transformity of Duplicates)

This is the information that has been 'extracted' from the highway in use, produced as maps, printed in many copies, and dispersed to Texas drivers. In Odum's words (1987:81), "the most important essence of the information on Texas highways that is shared information is printed in maps distributed to the public who use the maps in driving their cars. Emergy involved in the use of the highways is 15.1 E22 sej/yr being controlled by the maps produced each year with an energy content of each map":

$$(300 \text{ g map}) (4 \text{ kilocalories/g}) (4186 \text{ J/kilocalorie}) = 5 \text{ E6 J/map copy}$$

The population of Texas in 1986 was 15 million people and the number of maps in service was assumed to be 5 million maps. The transformity of highway maps is calculated as the emergy of highway use divided by the energy of 5 million copies of maps. Below is the calculation from the original endnotes, but the result reported on the graph was in error and has been corrected:

$$(15.1 \text{ E22 sej/yr}) / [(5 \text{ E6 copies}) (5 \text{ E6 J/copy})] = \underline{6.04 \text{ E9 sej/J}} \text{ (not } 8.1 \text{ E9 sej/J, as reported on the original graph (Figure 6), mistakenly duplicated from the last bar)}$$

This measure is equivalent to the many copies of specification books, above.

Note that the available energy of maps is

$$(5 \text{ E6 copies}) (5 \text{ E6 J/copy}) = \underline{2.5 \text{ E13 J/yr}}, \text{ and has been included on Figure 7.}$$

Sharing Information (Transformity of a Shared Original)

The *transformity of a shared original* is defined as "the total energy supporting the shared information divided by the energy flow for ONE copy. This measures what is required to maintain the shared status per unit of the information shared (1987, p. 47)."

If maps are replaced every three years, the yearly energy flow through maps is:

$$(5 \text{ E6 J/map}) (0.33 \text{ maps/yr}) = 1.83 \text{ E6 J/map/yr}$$

That energy flow is used for this last information calculation, solar transformity of the 'shared original':

$$(15.1 \text{ E22 sej/yr}) / (1.83 \text{ E6 J/copy}) = \underline{8.25 \text{ E16 sej/J}} \text{ (corrected from } 8.1 \text{ E16 sej/J)}$$

Notice in Figure 8 that the 'Map Original' value is shown leaving the process box (b) and flowing into box (c), which is the location for the production of 5 million map copies. In actual terms, this would be the order of events. In this calculation, however, the transformity for the 5 million maps is reported first, followed by the calculation for the 'shared original'. This is not significant; it is simply the result of the calculation method for 'shared original'.

Bar Graph Explanations

Energy Source, Fuels

Last, I will comment on the first bar in Figure 6. An explanation and calculation for that bar is not provided by Odum. My interpretation is that he simply wished to mark the lowest-quality essential energy input to highways, which was fuels, which he conceived as the primary energy 'source' that drove

all else. That interpretation comes from considering the systems diagram that he placed immediately below the bar graph in Figure 6. The 'source' symbol is below the first bar, labeled 'Energy Source, Fuels', a 'producer' symbol is below the second bar, labeled 'Production, Highways', and so on. Thus, simply put, fuel is the largest driving energy 'source' for the entire Texas system, within which is found the Texas highways. This bar is not included in my general interpretation of the study.

Solar transformity of 'Energy Source, Fuels':

5.3E4 sej/J