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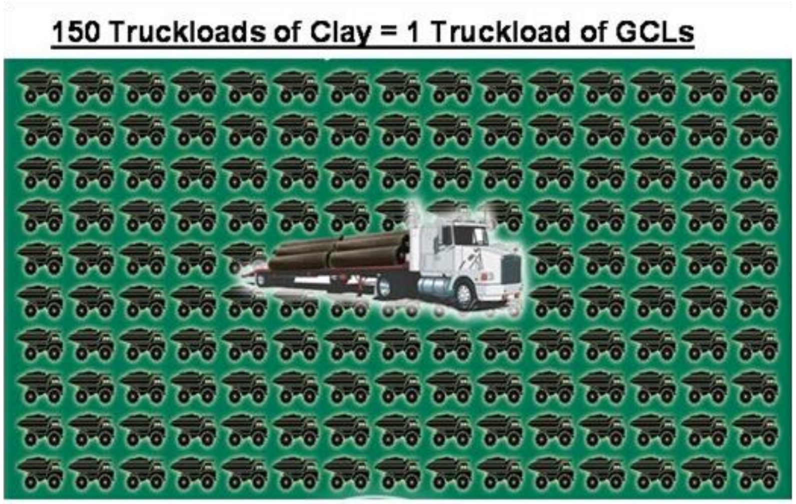
GSI White Paper #41

Relative Sustainability (i.e., Embodied Carbon) Calculations With Respect to Applications Using Traditional Materials Versus Geosynthetics



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Overview

Listening and reading the "news", there seems to be regular public criticism of all types of plastics insofar as long-term lifetime concerns regarding their post-use disposal. Rarely, if ever, is the distinction made as to which plastics are really necessary to society and which are indeed disposable. Of course, we in the geosynthetics area feel that the plastics that are used are indeed necessary and will be dependable for very long service lifetimes. Recent lifetime prediction data clearly justifies such longevity; see Koerner, et al. (2017). As such, our general rejoinder in the above discussion is that geosynthetics provide either…

(i) better and longer performance than traditional material solutions, or

(ii) provide less costly solutions than using traditional materials.

That said, we certainly could, and perhaps should, add enhanced "relative sustainability" to the above two items when dealing with geosynthetic applications. The quantification of such enhancement is the topic of this White Paper. In so doing, geosynthetic applications are compared insofar as their embodied carbon (also called carbon footprint) is concerned to the same applications using traditional construction materials such as concrete, steel, timber, clay or granular soils. At the outset some definitions of the interrelated terms used throughout this white paper are as follows:

- Sustainability – avoidance of the depletion of natural resources in order to maintain an ecological balance
- Embodied Carbon (EC) – refers to carbon dioxide emitted during the manufacturing, transport and construction of all building materials, together with end of life emissions.

- Carbon Footprint (or CO_2 Footprint) – the amount of carbon dioxide and other carbon compounds emitted due to the consumption of fossil fuels by a particular person, group or application.

This GSI White Paper addresses the topic of embodied carbon (or EC) by way of quantified calculations for a number of applications. Thus, comparisons for traditional civil engineering material systems can be compared on a numeric basis, as was graphically suggested by the figure on this front page.

Conceptually, embodied carbon for a particular geotechnical, transportation, hydraulic or geoenvironmental engineering project (or element of a project) is calculated by comparing the amount of carbon dioxide in the conventional materials design compared to that of the geosynthetic design.

The concept of embodied carbon, using carbon dioxide calculations, provides a measure of the cumulative energy (and hence carbon emissions) required to produce, deliver and use the various materials concerned. For example, the carbon embodied in concrete comes from the extraction, processing and transportation of cement and aggregate constituents. The embodied carbon in a concrete structure encompasses all these components insofar as the finished product is concerned, including its transportation to the specific site. Similarly, the embodied carbon in steel reflects the mining of iron ore, its subsequent transportation and manufacture into steel, plus further transportation and processing of the final product as delivered to a site. In a like manner for geosynthetics, the capture of oil or gas, its transportation to a refinery where a particular polymer is made, and subsequent manufacture into a geosynthetic product also has a quantifiable embodied carbon associated with it.

Lastly and for all materials, the actual construction activity must also be considered in evaluating its embodied carbon, to ensure that a fully balanced assessment of all alternatives is made. This takes into account all of the directly applicable material and labor requirements.

As will be seen, the traditional civil engineering materials of concrete, steel, timber, clay or gravel, in their structural forms, contribute greatly to the embodied carbon of any construction project. By avoiding or minimizing the use of these materials through using a comparable geosynthetic material, the latter will help to reduce the inherent embodied carbon of these same projects. Of course, the geosynthetic solution must be calculated using the same procedures as the traditional material solution.

Embodied Carbon Data Bases

Several organizations have published data bases of "embodied carbon" in units of Kg CO_2/Kg for most construction materials. Most importantly are the U.S. Environmental Protection Agency (2006), the University of Bath (2008) and Stucki, et al. (2011); the latter on behalf of the European Association of Geosynthetic Manufacturers. In particular, some embodied carbon data is available and reprinted here as Tables 1(a) for traditional materials and Tables 1(b) and 1(c) for geosynthetics.

Table 1(a) – Embodied Carbon Values for Different Traditional Construction Materials (Univ. Bath, 2008)

Construction Material Type	Embodied Carbon (Kg CO_2/Kg)
Sand	0.005
Compacted General Soil	0.023
Concrete	0.77 to 1.39
Masonry Blocks	0.81
Timber	0.45 to 0.86
Steel	1.24 to 2.7
Water	0.2
Wood	1.7
Aluminum	9.3

Table 1(b) – Embodied Carbon Values for Different Plastics and Plastic Products (Hammond & Jones, 2011)

Material	Embodied Carbon (Kg CO_2/Kg)	
General Plastic	3.31	-
General Polyethylene	2.54	-
High Density Polyethylene (HDPE)	1.93	1.91
HDPE Pipe	2.52	-
Low Density Polyethylene (LDPE)	2.08	2.06
LLDPE Film	2.60	2.66
Polypropylene, Orientated Film	3.43	-
Polypropylene, Injection Moulding	4.49	-
Polypropylene, Granules	-	1.98
Polyester, Granules	-	2.70
Polyester, Granules (bottle grade)	-	2.90

Table 1(c) – Embodied Carbon Values for Nonwoven Geotextiles (Raja, et al., 2015)

Geotextile Type	Polymer Embodied Carbon (tCO_2/t)	Conversion of Granules to Fibers (tCO_2/t)	Manufacturing Carbon Emissions (tCO_2/t)	Total Embodied Carbon (tCO_2/t)
Nonwoven Needle Punched	1.983	0.241	0.053	2.28
Nonwoven Thermally Bonded/Needle Punched			0.189	2.42

Embodied Carbon Calculations of a Working Blanket (Dixon, et al. 2016)

As an example of how this type of data is used in a calculation for a specific application, we use a numeric example from Dixon, et al. (2016). It has to do with the construction of a working blanket for temporary support of heavy construction equipment. Two solutions are considered; one with geosynthetic reinforcement, the other without. The calculations are for a working platform to support 1160 kN from a Piling Rig mast foot pad. Assuming Terzaghi's bearing capacity equation gives a load spread of 45 degrees, a reduction in soil thickness of 50%

can be realized with a layer of geosynthetic reinforcement. Again, the purpose of this example is to carry out an EC comparison of the two solutions and is based on an example calculation carried out for a specific site. Should the loadings, subgrade, aggregate or calculation methods differ; the calculated EC value will also change. This highlights the importance of considering each project on a case by case basis.

A 500 g/m^2 polyester woven geotextile has been designed for the geosynthetic reinforcing layer. This calculation example also highlights the challenge of selecting an appropriate EC value for the geotextile. Raja, et al. (2015) calculated EC for a polyester geogrid of 2.36 tCO$_2$/t. However, there is no data available for woven polyester geotextile. For the purpose of this calculation the value of 2.36 tCO2/t is adopted, however, the potential source of error in calculations must be acknowledged. The input parameters are shown in Table 2(a).

The calculated EC values for the two working platform solutions are presented in Table 2(b). The 50% reduction in aggregate gives a 6.00 kgCO$_2$ reduction in EC per m^2 of working platform. There is an additional savings of 2.34 kgCO$_2$ from transport emissions, however, this is sensitive to distance from the site. The EC of the geosynthetic component is 1.19 kgCO$_2$. Overall, it is seen that a 43% EC reduction is calculated using the geosynthetic solution.

The EC of the geosynthetic component in this example would have been further reduced from 1.19 kgCO$_2$ to 0.98 kgCO$_2$ if the lower value of 1.94 tCO$_2$/t was employed as in the WRAP (2010) studies. For this example, the savings are less dependent on the EC of the geosynthetic component since the aggregate EC dominates the overall EC values.

Table 2(a) – Input Values for Geosynthetic Solution for Working Platform

Property	Value	Units
Polyester geosynthetic cradle to gate EC value (Raja, et al. 2015)	2.36	$kgCO_2$ /kg
Aggregate cradle to gate EC value (Hammond and Jones, 2011)	0.005	$kgCO_2$ /kg
Geotextile Transport Distance	200	km
Aggregate Transport Distance	25	km
Unit weight of selected non-cohesive soils	2000	kg/m^3
α = Fuel consumption of rigid HGV	3.33	km/l
β = CO_2 emissions per litre of fuel	2.60	$kgCO_2$/litre

Table 2(b) – Calculated EC Values for Aggregate vs. Geotextile Reinforced Working Platform

	1.2 m Aggregate EC ($kgCO_2$)	0.6m Aggregate + Geotextile Reinforcement, EC ($kgCO_2$)
Aggregate (cradle-gate)	12.00	6.00
Aggregate Transport	4.68	2.34
Total Aggregate EC (cradle-site)	**12.00**	**8.34**
Geosynthetic EC (cradle-gate)	-	1.18
Geosynthetic Transport	-	0.008
Total Transport	**4.68**	**1.19**
Total	**16.68**	**9.53**

The WRAP Report on Calculations Which Focus on Walls and Slopes

Quantitatively, the numeric decrease in embodied carbon using geosynthetics solutions for walls and slopes was clearly shown in a report titled, “Sustainable Systems in Civil Engineering Applications” by the Waste and Resources Action Program (WRAP) in May, 2009. The report was authored by representatives of 16 U.K. organizations of which one-third were involved in geosynthetics. In it are five worked-out case studies; see Table 3. They address both walls and slopes and show that when replacing traditional material solutions with geosynthetic materials, costs are greatly reduced (as expected) and the embodied carbon, i.e., CO_2 footprint, is reduced even moreso. The five different case history results for both costs and carbon footprint are shown in the following table.

Table 3 - Case Study Results from WRAP Report (May, 2009)

Case History	Traditional Approach		Geosynthetic Approach	
	Cost (K)	CO_2 Footprint (tons)	Cost (K)	CO_2 Footprint (tons)
#1 Slope Stability	$571	157	$23	21
#2 Bridge Approach	$1,282	500	$574	346
#3 Crib Wall	$51	35	$41	11
#4 Sheet Piling Wall	$246	433	$121	69
#5 Concrete Wall	$98	107	$20	20

Case history #1 concerned a soil slope stability calculation comparing the original gabion wall design using quarry imported gravel, to a reinforced soil slope with geogrids. The latter used site available soil in the reinforced soil zone. The above table indicates an 87% decrease in carbon footprint using the geosynthetic approach.

Case history #2 concerned a new bridge approach embankment originally designed with imported gravel fill compared to using a locally available fine-grained soil reinforced with geogrids. The above table indicates a 31% decrease in carbon footprint using the geosynthetic approach.

Case history #3 concerned the rebuilding of a section of collapsed brick retaining wall. The alternatives were reconstruction using a reinforced concrete cantilever retaining wall versus a concrete crib wall filled with locally available soil. The above table indicates a 69% reduction in carbon footprint using the crib wall.

Case history #4 concerned the refurbishing of a deteriorated retaining wall with either an interlocking steel sheet pile wall or a pre-cast concrete faced panel wall with geosynthetic strip reinforcement. The above table indicates an 84% reduction in carbon footprint using panel wall with strip reinforcement.

Case history #5 concerned a new retaining wall to support a parking area. The alternates were a traditional reinforced concrete retaining wall versus a masonry block wall reinforced with geogrids. The above table indicates an 81% reduction in carbon footprint using the reinforced masonry block alternative.

The detailed calculations used to arrive at the respective carbon footprints for each of the different alternative designs are given in the WRAP report.

The GSI Conference on "Optimizing Sustainability Using Geosynthetics" Including Calculations of a Landfill Cover System

The previously discussed WRAP Report stimulated an entire conference, hosted and organized by the Geosynthetic Institute, on the relative sustainability issue. It focused entirely on different geosynthetic related alternatives compared to natural materials (aka, traditional) solutions in many common applications. The conference proceedings included twenty papers, the keynote speaker being Dr. Russell Jones, who was one of the authors of the WRAP program. The average carbon savings of the conference papers, grouped by application area are given in Table 4. Within the 25 analyzed applications, an overall average of 65% reduction in carbon footprint using geosynthetic related alternatives was realized.

Table 4 – Case Studies from GRI-24 Conference (March, 2011)

Application Area	No. Cases Described	Average Carbon Savings
Walls	6	69%
Embankments and Slopes	4	65%
Armoring	4	76%
Landfill Covers	3	75%
Landfill Liners	2	30%
Retention	3	61%
Drainage Pipe	3	40%
TOTALS	25	65%

One paper by the lead author of this White Paper focused on landfill covers. It compared a traditional layered soil cover with an exposed geomembrane cover. Calculation details arriving at an 82% reduction in embodied carbon for the exposed geomembrane cover follow.

When comparing a traditional landfill cover to an exposed geomembrane cover, the elimination of surface layer, protection layer, and drainage layer will economically favor the exposed geomembrane solution. That said, the exposed geomembrane solution will still require a gas collection layer and an underlying foundation layer. It will also require a thicker (hence, more robust) geomembrane and these considerations will be reflected in the final results.

In the following <u>cost analyses</u>, a landfill cover in the Philadelphia, Pennsylvania region is envisioned. The estimated installed unit prices are current as of 2010; see Table 5. These unit prices are then extended to a hectare as shown in Figure 1. As anticipated, the exposed geomembrane cover is only a fraction (30%) of the cost of a traditional final cover over the 30-year period envisioned. Of course, this leaves open the question of performance after 30-years. If the traditional final cover and exposed geomembrane covers are both depreciated at this time, the cost comparison is valid. If, however, the traditional final cover is still functional, or is partially functioning and can be reasonably remediated, the cost comparison is not valid. In a converse sense, the very large settlement of the waste mass at the end of this 30-year period is recoverable for additional waste placement. This cannot be accomplished if a traditional final cover is deployed. In contrasting both of these issues it is fully realized that site-specific conditions will prevail on the basis of cost.

A flow-chart containing each layer will be used to compare the embodied carbon of a traditional final cover and an exposed geomembrane cover. Data on carbon-values were obtained from the U.S. EPA (2005) and the University of Bath (2008); see Table 6 where the units are Kg CO_2/Kg of specific materials, as well as Kg CO_2/gallon of diesel fuel for the transportation costs. The flow chart of Figure 2 presents the calculated values of kilograms of CO_2 liberated for the respective materials per square meter and then extended per hectare. Diesel fuel is based on truckloads of the various materials from their estimated sources to the hypothetical site in the Philadelphia, Pennsylvania area. These two values (materials and transportation) are then added and transposed onto Figure 2 for each layer of material of the two respective alternatives and totaled. Here it is seen that the CO_2 footprint of the exposed geomembrane cover is only 18% of the traditional multi-layered cover as traditionally constructed. It is felt that this worked-out example is typical of many such related sustainability calculations.

Table 5 – Estimated Installation Costs for Various Layers of Landfill Cover Alternatives

Layer (Top-to-Bottom)	Traditional Landfill Cover Costs ($/$m^2$)	Exposed Geomembrane Cover Costs ($/$m^2$)
Seeding and vegetation	0.90	-
Topsoil; 150 mm	36.00	-
Protection Soil; 750 mm	22.80	-
Drainage composite; 6.3 mm	7.30	-
Geomembranes; 1.0 and 1.5 mm	6.50	9.20
GCL-reinforced	4.20	4.20
Geotextile; 520 g/m^2	3.80	3.80
Soil foundation layer	9.20	9.20
Waste proof rolling	0.90	0.90
TOTALS	91.60	27.30

Table 6 – Embodied Energy and Carbon Values for Soil and Geosynthetic Layers of Landfill Cover Components;
(ref. U.S. EPA (2005), University of Bath (2008), and the Stucki, et al. (2011)

Layer Top-to-Bottom	Carbon Values (Kg CO_2/Kg material)
seeding and vegetation	0.190 Kg CO_2/Kg
topsoil	0.090 Kg CO_2/Kg
protection soil	0.023 Kg CO_2/Kg
drainage composite (PE)	1.7 Kg CO_2/Kg
geomembrane (PE)	1.7 to 2.0 Kg CO_2/Kg
geosynthetic clay liner	0.22 Kg CO_2/Kg
geotextile (PP)	2.7 Kg CO_2/Kg
soil foundation	0.023 Kg CO_2/Kg
proof rolling	0.045 Kg CO_2/Kg
diesel fuel	10.1 Kg CO_2/gallon

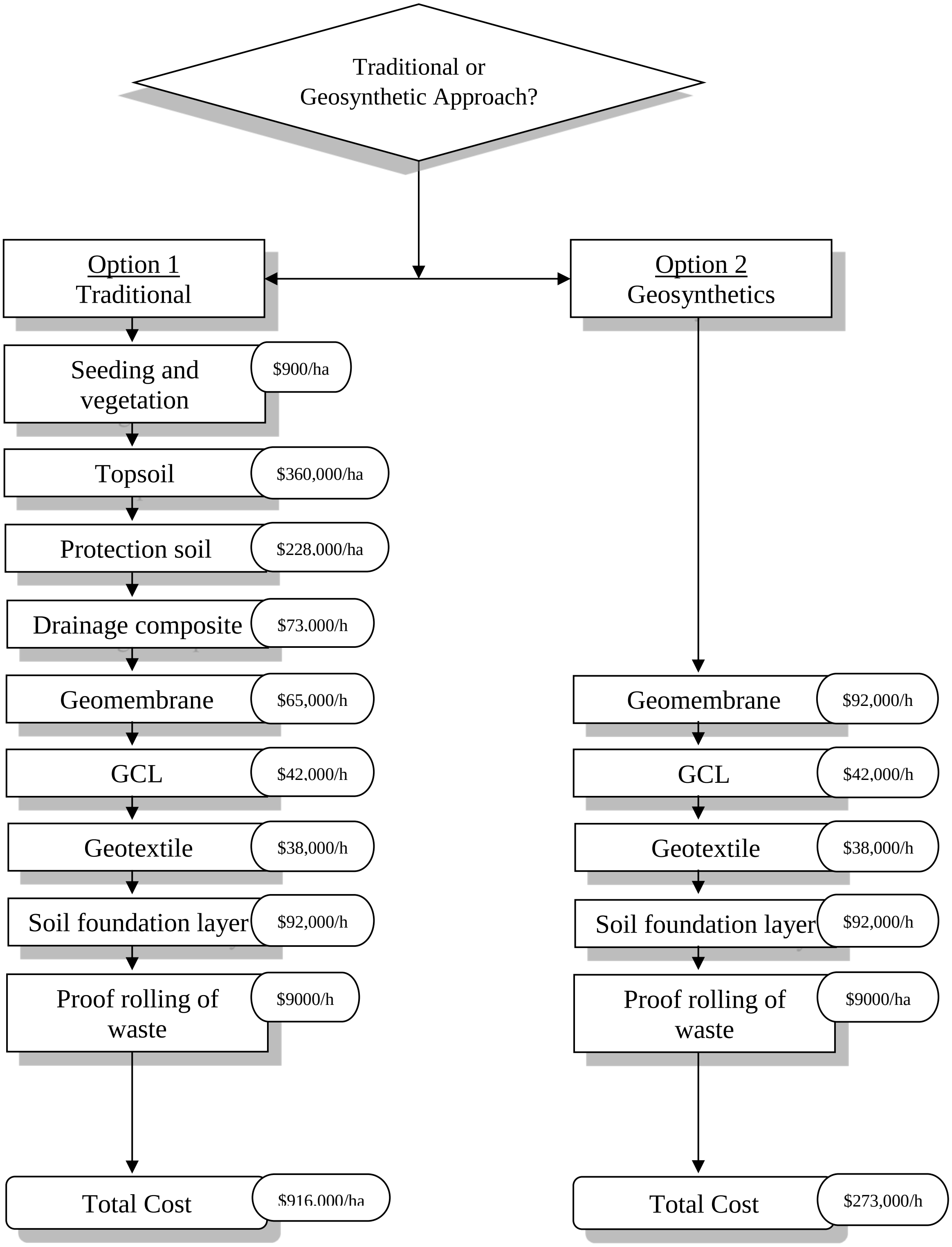

Figure 1 – Flowchart comparing costs in units of “$/ha”.

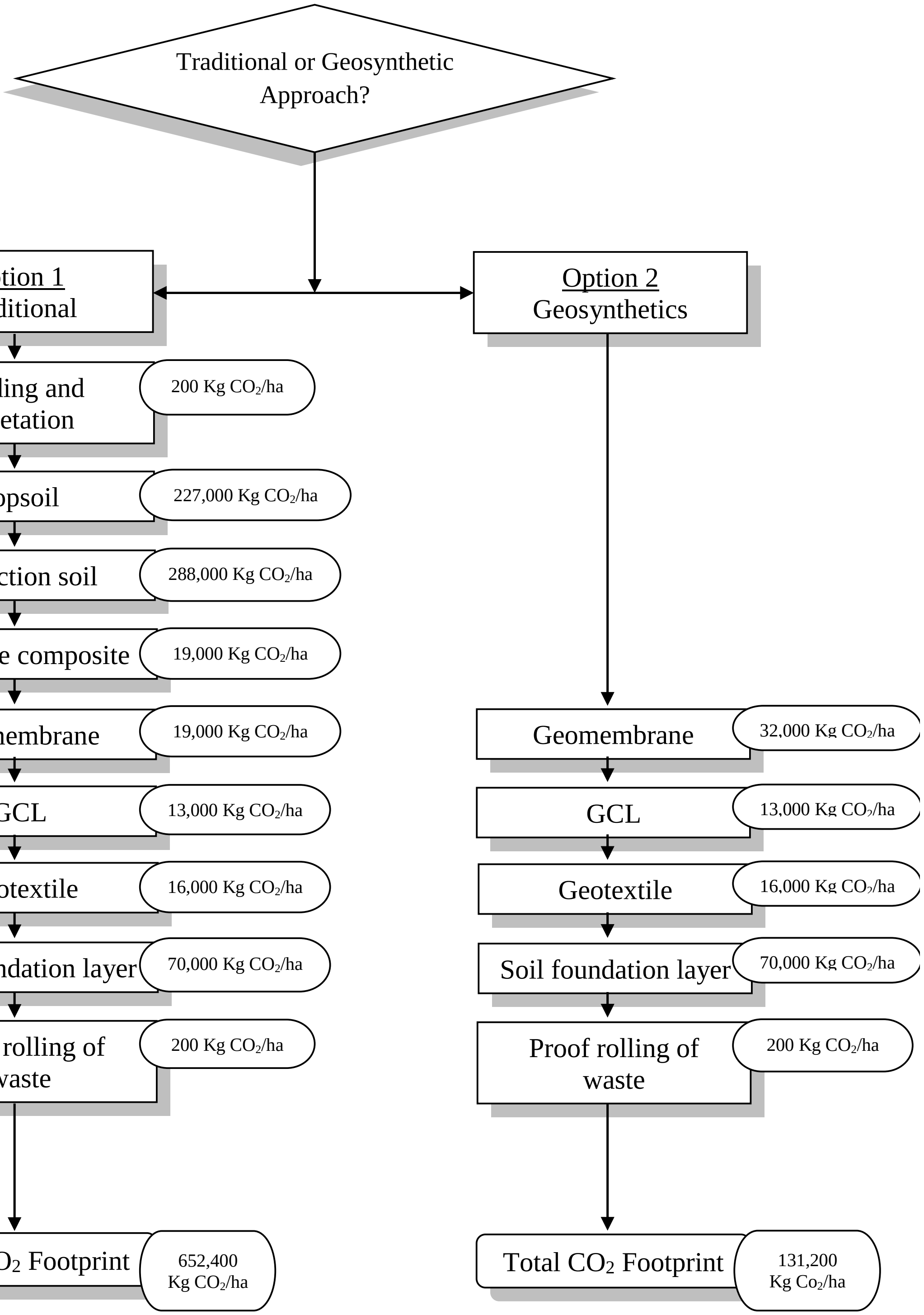

Figure 3 – Flowchart comparing carbon footprints in units of “Kg CO_2/ha”

Summary and Conclusions

In preparing this white paper, two overall items are abundantly clear. First, the data base and calculation procedure for assessing carbon footprint for most construction projects is presently available. Second, America is very much behind our European colleagues in providing, even routinely providing, such information. In the opinion of the authors of this white paper, such calculations for geosynthetic systems should always be provided. Clearly, the “winner” using either traditional materials of concrete, steel, timber, clay or granular soils compared to a comparable geosynthetic alternative can be made. The option with the better relative sustainability should be used, and even further should be used to complement the cost and durability of the preferred solution and its alternatives as was mentioned in the overview section.

The reluctance for making sustainability calculations in America most likely comes from the lack of governmental mandates at the federal, state and/or local levels. While reluctance exists at this point in time, private owners and developers could well set-the-tone for requiring such calculations. In so doing, at least this segment of our application spectrum would be showing a leadership position. As an example, our waste disposal industry, where geosynthetics play a pivotal role, could profit from some favorable publicity in order to counter the many negative statements and opinions which are commonplace. This statement also carries over to the private development sector as well. Complaints about random building development are common, so why not promote that such development carries with it the maximum relative sustainability of all of the many possible alternatives?

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