Comparison of Carbon Footprints for Various Stormwater Retention Systems

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ABSTRACT

Construction materials continue to be a major source of greenhouse gases (GHG) based on the fossil fuels used in their production. As the amount of greenhouse gases generated each year continues to increase, there needs to be a more conscious effort to provide alternatives with lower carbon footprints. Geosynthetics have always provided cost effective alternatives to traditional construction materials but now can be shown to provide sustainable alternatives as well. One of faster growing areas within construction is stormwater management. The USEPA mandates storage and infiltration on all new construction projects and leaves the design of these systems to the local engineer. This paper reviews the geosynthetic choices and makes a comparison between the amounts of CO_2 generated by each system.

Carbon Footprint

In the U.S., energy-related activities account for over 85 percent of human-generated greenhouse gas emissions, mostly in the form of carbon dioxide emissions from burning fossil fuels (see figure 1). More than half the energy-related emissions come from large power plants, while about a third comes from the transportation industry. Industrial processes (such as the production of cement, steel, and aluminum), agriculture, forestry, other land use, and waste management are also significant sources of greenhouse gas emissions in the United States.

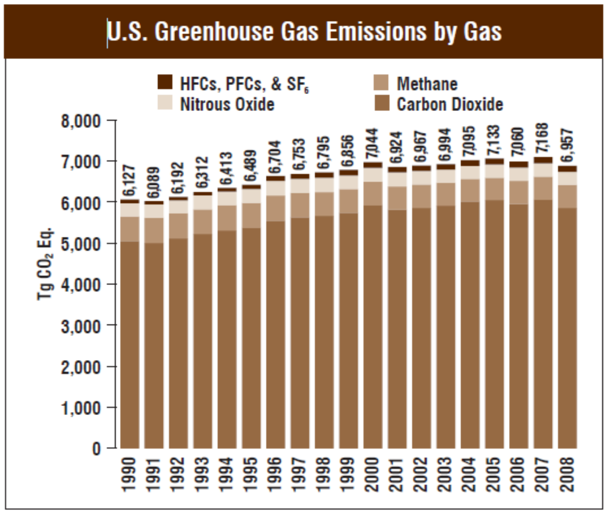


Figure 1. *US EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 - 2008*

For a better understanding of where greenhouse gas emissions come from, Federal, State and local governments prepare emissions inventories, which track emissions from various parts of the economy such as transportation, electricity production, industry, agriculture, forestry, and other sectors. The EPA publishes the official national inventory of US greenhouse gas emissions and the latest greenhouse gas inventory shows that in 2008 the U.S. emitted slightly less than 7 billon metric tons of greenhouse gases. A million metric tons of CO_2 equivalents is roughly equal to the annual GHG emissions of an average U.S. power plant.

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are for the most part, solely a product of industrial activities. From the pre-industrial era (i.e., ending about 1750) to 2005, concentrations of these greenhouse gases have increased globally by 36, 148, and 18 percent, respectively (IPCC 2007). Figure 2 shows the cumulative change in annual Greenhouse emissions from 1990 to 2008.

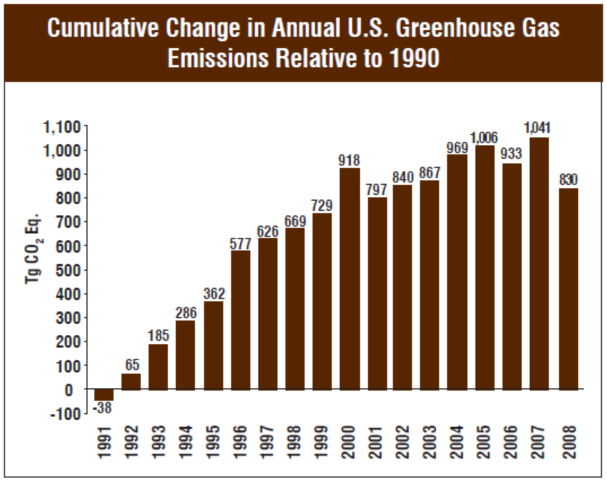


Figure 2 *US EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 - 2008*

As shown in Figure 3, 85.1% of all emissions sources of CO_2 come from fossil fuel combustions. It is interesting to note that the drop off in GHG emissions in 2008 is related to the economy.

For the purposes of this paper, the focus will be on the amount of CO_2 created during the manufacturing of various stormwater retention systems and the amount of CO_2 created from diesel fuel consumed during construction.

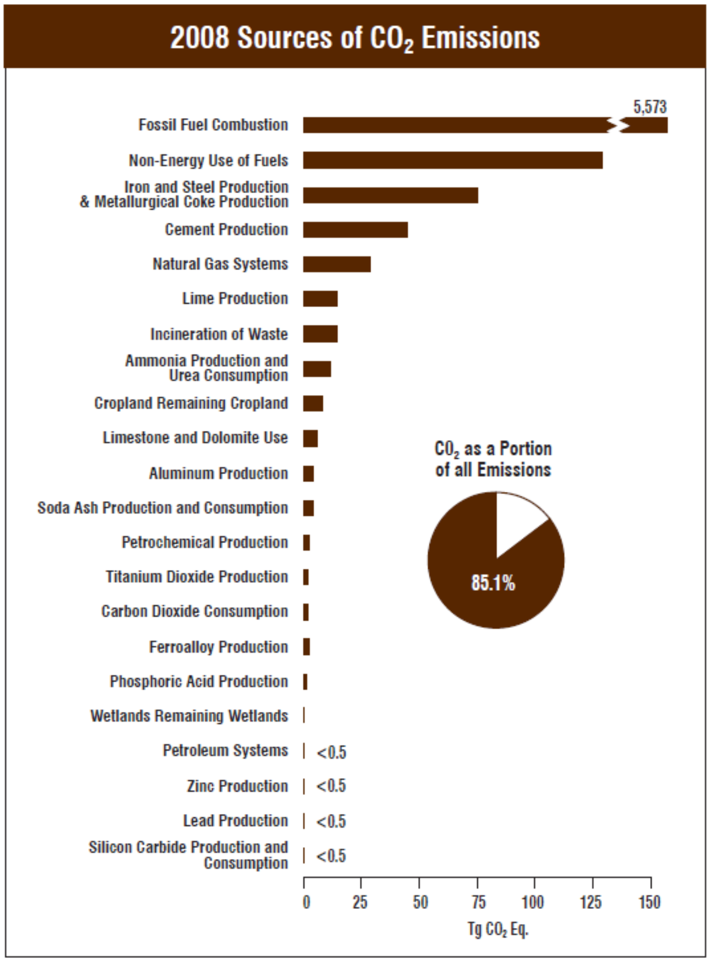


Figure 3 *US EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 - 2008*

Stormwater Retention Systems

Stormwater runoff is created from rain events and snowmelts that flow over impervious areas and are not allowed to infiltrate back into the ground and recharge the water table. One of the first controls put on stormwater came through the Clean Water Act, and the National Pollutant Discharge Elimination System (NPDES) permit program. The NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Most States are authorized to implement a NPDES permitting program.

National Pollution Discharge Elimination Systems and Stormwater Ordinances

The definition given to NPDES is as follows; “a national program that issues, modifies, revokes and reissues, terminates, monitors and enforces permits that are required when there is a discharge of pollutants” (Dodson, 1999). NPDES permits may be issued for industrial reasons or for construction purposes. A point source discharge is another reason to have a NPDES permit. The EPA defines a point source as follows:

> "…any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows form irrigated agriculture or agricultural storm water runoff." (EPA, 1999)

As stated above, the definition leaves the EPA a broad description for a point source discharge so that there can be little defense against saying the site has no point source discharge.

NPDES permitting along with public knowledge of stormwater issues led local municipalities to adopt their own stormwater ordinances. These ordinances can control many aspects of the construction design from pipe sizing to maximum amount of impervious cover. With these stipulations on stormwater management, Best Management Practices (BMP's) are needed to meet or lower current existing conditions.

Types of Best Management Practices

- Infiltration Beds – Grass swales and porous pavements
- Filtration – Sand filters, vegetated filter strips, etc.
- Retention/Detention Basins – Dry ponds, wet ponds and inline storage

Structural BMP's are defined as any BMP that involves man made structure or alteration that would improve the quality of the stormwater. The huge growth of the stormwater market has created a vast amount of companies and products to meet the requirements and function of structural BMP's. However, there are a few BMP's that are used more often than others based on their ease of design and cost. One BMP that is used frequently is the lined retention pond. Retention ponds are inexpensive but take a lot of space and have some negative impacts on the environment due to the exposed standing water. Lined retention ponds have the ability to treat large areas of runoff and reduce the amount of sediment that is released to receiving waterways.

An infiltration basin (an unlined retention pond) is another structural BMP that is often used in site development. The infiltration is usually limited to a location that is not near bed rock or foundations. Infiltration basins can handle a high sediment input but must be designed for proper maintenance. Also the infiltration basin also recharges the groundwater and reduces the volume released downstream.

The most widely used systems currently are underground storage systems since they provide the most amount of variability. These systems included stone beds wrapped in filter fabrics, corrugated steel or plastic pipes with a stone envelope around each pipe, half arch plastic modules backfilled with crushed stone, concrete vaults of various sizes and multiple types of plastic cubes used to maximize void space see Figure 4.

Figure 4 *(a) Retention Pond (ACF Environmental), (b) Corrugated Metal Pipe (Contech), (c) Arch Chambers (Stormtech®), (d) Conspan® (Contech)*

CURRENT PRACTICE

The volume of stormwater required to be stored on site continues to increase as impervious surfaces are constructed. Most regulations require the runoff after construction not to exceed the volume of runoff pre-construction. This creates the need for large volumes of storage on site.

Traditional storage methods relied on above ground detention and retention basins. These basins require a large footprint. In an effort of optimize the value of real estate there has been a tendency to put the stormwater storage systems underground. This trend is seen more in urban areas where the value of real estate is high and the areas available for development are small.

Although there are many types and variations of structural BMP's including detention and retention basins, this paper will focus on structural BMP's used for underground stormwater storage. Unlined storage systems will infiltrate and allow captured stormwater to percolate into the subsoil, and offer efficient and economical groundwater recharge. In addition to reducing stormwater flows from the site, recharge systems also present water quality benefits through the soil's natural filtering ability

Corrugated Pipe

The most commonly used system to date is corrugated metal pipe (CMP) and Corrugated Plastic Pipe (CPP). The pipe are connected in rows and tied into a manifold for inlet flow as shown in Figure 5.

Figure 5. *Corrugated Metal Pipe (CMP) (Contech)*

Perforated CMP/CPP is installed and typically enclosed with a nonwoven geotextile designed based on site specific soils to prevent clogging. This provides long-term infiltration and protects against soil migration. The system is then *backfilled* with uniformly graded stone. Typically, the same type of material used around drainage pipes is excellent for recharge systems. Standard pipe wall perforations (3/8" diameter holes meeting AASHTO M-36, Class 2) provide approximately 2.5% open area. This provides adequate recharge flow for most soils. There are minimum spacing requirements between pipes to allow for proper backfill enabling the structure to develop adequate side support. The material specified for backfill is usually AASHTO M-145, A-1, A-2, A-3 granular fill. Closer spacing is possible depending on quality of backfill and placing and compaction methods. A schematic is given in Figure 6.

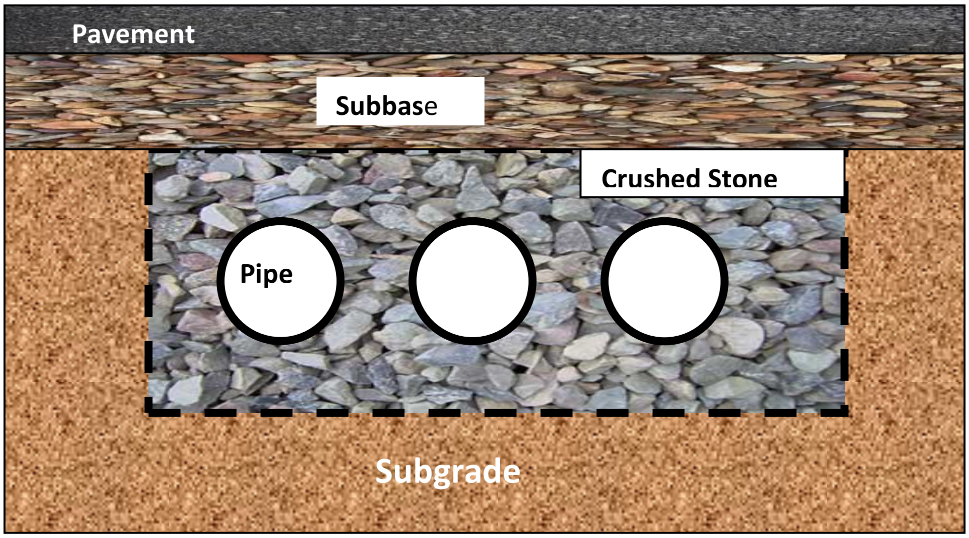


Figure 6. *Schematic of Corrugated Pipe Storage System (N.T.S.)*

Corrugated Arch Chambers

One of the advantages of arch chambers is that they are flexible and can be configured into beds or trenches of various shapes and sizes. These systems can be installed by hand as shown in figure 7.

Figure 7. *Installation of Corrugated Arch System (Stormtech®)*

These systems require clean angular stone below, between and above the chambers. The storage capacity is calculated by using both the void space within the chambers and 40% porosity within the stone. The chambers are installed with a minimum six inches spacing between each unit and detailed as shown in figure 8.

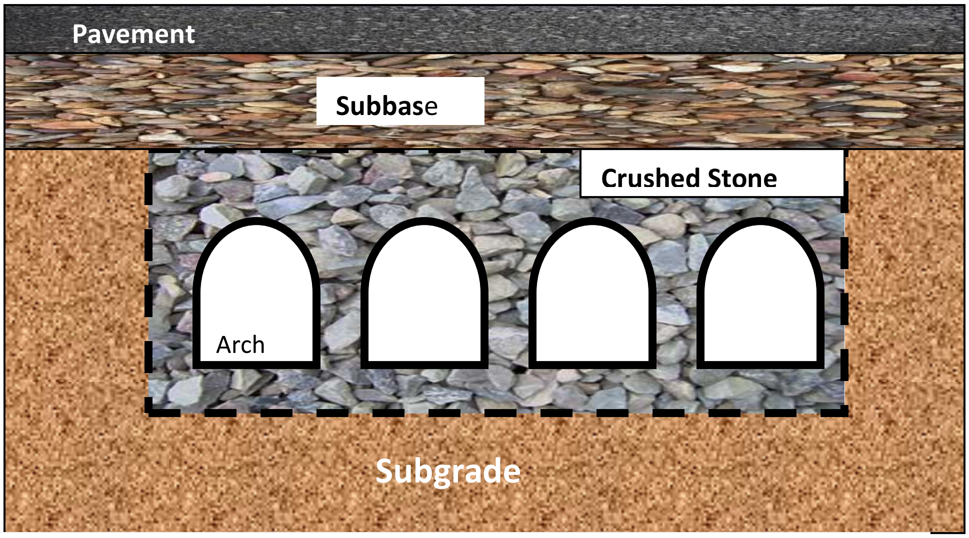
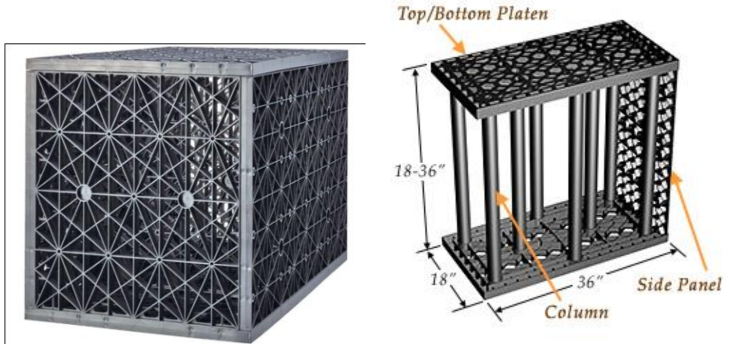


Figure 8. *Corrugated Arch Installation Details*

This spacing allows for soil arching of the angular stone between arches. The soil arch developed around the chamber provides the structural integrity required to support the pavement system above.

Plastic Stormwater Modules

Plastic modules are used as alternates to corrugated pipe and corrugated arch systems. There are over a dozen different manufactures of plastic modules for stormwater storage. Several examples are given in Figure 9. These systems are the most efficient in terms of voids space. They vary from 90% to 95% void space, are easily assembled in the field, light weight and some are made from recycled materials. The high void ratio reduces the amount of excavation required on jobsite and reduces the footprint required to install. The modular design allows the product to be shipped assembled or unassembled to jobsites to be more cost effective. They are very lightweight and can be installed by hand so heavy equipment is not required. The modular units can be stacked upon each other or installed in various patterns making it easier to work around utilities and other obstructions.



(a) Raintank® **(b) Brentwood Industries®**

(c) Aquacell® **(d) Cudo®**

Figure 9. *Various Examples of Plastic Stormwater Modules*

Excavations for the plastic modules are limited to the volume required for storage plus any backfill required by the manufacturer. A typical cross section is shown in Figure 10.

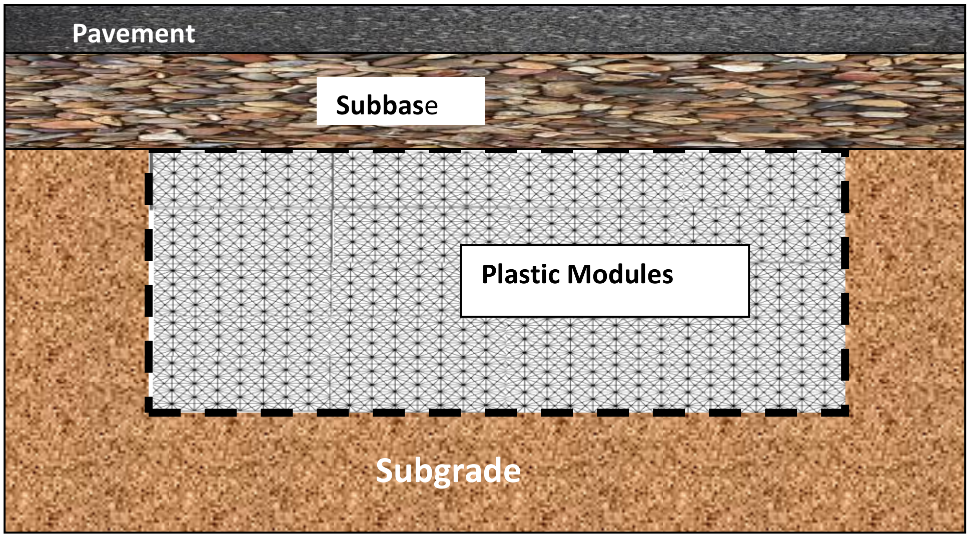


Figure 10. *Typical Cross Section of a Plastic Stomwater Module*

GeoStorage®

GeoStorage® is a new underground stormwater detention system creates a large storage chamber utilizing geosynthetics, stone and concrete slabs. A geotextile or geomembrane liner system is installed within an excavation. Around the perimeter of the excavation, walls are constructed with geosynthetic reinforcement and open-graded stone to create a large underground chamber. Inlet and outlet pipes extend through the perimeter liner system and wall face into the open chamber. A reinforced concrete roof is installed over the chamber and supported by the perimeter abutment/walls. A schematic of the system is shown in figure 11.

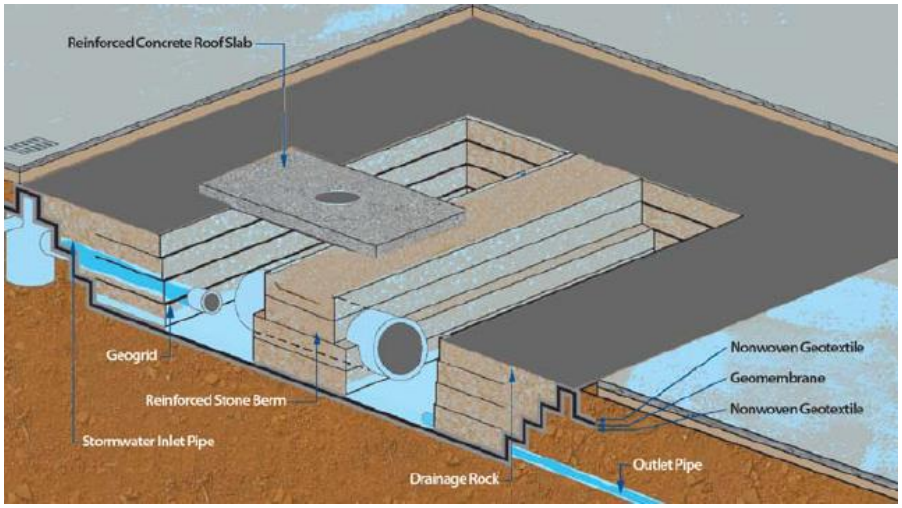


Figure 11. *GeoStorage® schematic*

Calculations

Calculating the carbon footprint of each system requires the breakdown the materials used in the construction of each system and the amount of earthmoving equipment required to install each system. Once the materials are known, a carbon inventory of each material must be calculated. The Department of Mechanical Engineering at the University of Bath in the UK developed the "Inventory of Carbon & Energy (ICE)". The ICE provides values for the amount of carbon released to produce various materials. It is important to note that the design life of each material must be accounted for as well as the amount of material wasted during production to get a full account of material used. Other factors include what type of maintenance is required for each system. Table 1 lists values used to calculate the carbon footprint.

Table 1. *CO_2 values used for calculations*

Material	**kg of CO_2/kg of material**
General Aggregate	0.017
Prefabricated Concrete	0.215
HDPE	1.6
HDPE Pipe	2.0
Polypropylene	2.7
Injection Molded PP	3.9
Recycled Polypropylene	1.4

Additionally, the shipping required for each system must also be part of the calculation.

Diesel fuel for equipment and transportation is 10.1 kg CO_2/gallon

The following assumptions were made for comparative purposes.

- All excavated materials remained on site
- All stone required was delivered from quarry within 30 miles
- All material deliveries where made within a 100 mile radius
- All systems are wrapped in a 200 gram nonwoven geotextile
- All pipes were designed for infiltration
- Both CMP and CPP are 48 inch diameter
- The volume of stormwater storage is 10,000 cubic feet
- Recycled plastics used 2.5kg less CO_2

Each manufacturer provides specific guidelines on the installation of each of their systems. Table 2 was developed using these guidelines and where based on building a stormwater system capable of storing of 10,000 cubic feet of stormwater.

Table 2. Comparison of Construction Measures for Each System

System	Number of Units	Material	Total Weight kg (lbs)	Volume of Stone CY	Volume of Excavation CY	Equipment Hours	Trucks required for delivery
Plastic Module	2,253	R-PP	31,531	310	726		1
CMP	32	Steel	44,800	402	682		4
CPP	32	HDPE	19,200	402	682		
Arch Chamber	134	PP	10,050	580	826		1
GeoStorage	8	Concrete	156,240	370	592		8

Once the list of materials for each system is calculated and the fuel required to deliver and install the system must be calculated. These values are then used with the data from Table 1 to create the totals in Table 3.

Table 3 *Totals of calculations for each system*

Stormwater Retention System	**Total Amount to CO2**
Plastic Stormwater Modules	29,340
Corrugated Plastic Pipe	186,174
Corrugated Steel Pipe	571,227
Corrugated Arch Chambers	28,578
GeoStorage®	25,470

Conclusions

The results of the calculations for each system show that there can be a vast difference in the amount of CO_2 generated depending on what system is selected. The calculations revealed that the type of material combined with the total weight of material used is the significant factor for the total CO_2 generated. Steel and Plastics both have relatively high amounts of CO2 in their production although the plastic stormwater modules are more efficient in the amount of plastic used for each unit.

It should be stressed that the evaluations did not consider the structural strength of these systems or the cost per unit volume of storage. These factors along with maintenance and system design life should also be considered when evaluating various systems.

REFERENCES

US EPA Greenhouse Gas Emissions

US EPA 2010 U.S. Greenhouse Gas Inventory Report

http://www.epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_ExecutiveSummary.pdf

DYODS, Design Your Own Detention System, Contech Construction Products