Integrando los vertederos en la economía circular

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Carbon Footprint and Sustainability of a Geosynthetic Clay (GCL) Liner in a Landfill Cap

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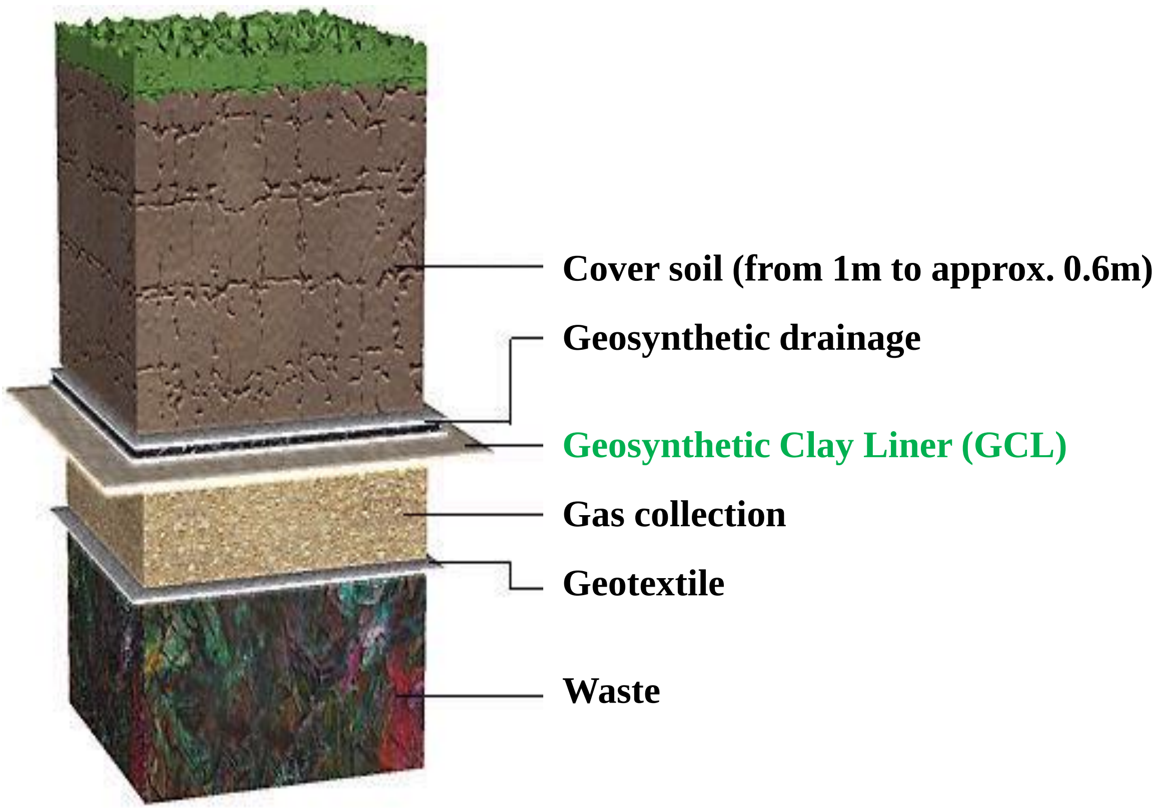
Chairman: CEN TC189/WG6 Barriers; ASTM D35.04 GCLs, IGS Barrier Systems
Task group leader: ISO 221 WG6/PG9 Designing with Barriers
Member: BoA Geosynthetic Institute, IGS Council, ISO 221 WG2, Technical Advisory Committee Geosynthetics,
Geosynthetics Lecturer: University of Applied Sciences Bielefeld & University of Applied Sciences Ostwestfalen-Lippe
Honor Lecture: 2nd Koerner Lecture at GeoMEast 2018

Carbon Footprint and Sustainability of a Geosynthetic Clay (GCL) Liner in a Landfill Cap

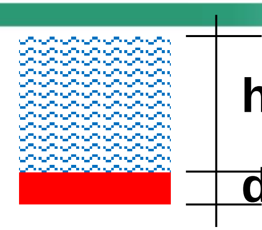
1. Introduction and Simple Basic Facts
2. What is Carbon Footprint and Sustainability
3. Environmental Product Declaration
4. Cumulated Energy Demand
5. Fresh Water Aspect
6. Summary



Common containment regulations require different cap/cover sealing systems for different containment classes (here: single GCL liner)

1. Typically a GCL Performs Similar or Better than a Compacted Clay Liner (CCL)

$Q = A * k * i$ [m³/ha/day] with: $i = (d + h / d)$



Permeation (according to Q = k · i · A) calculated in [m³/ha/day]

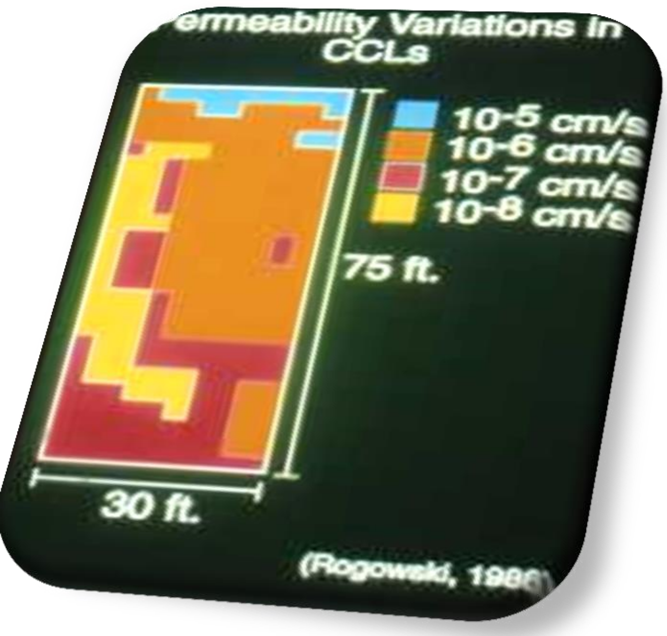
Q = permeation k = permeability i = gradient A = area

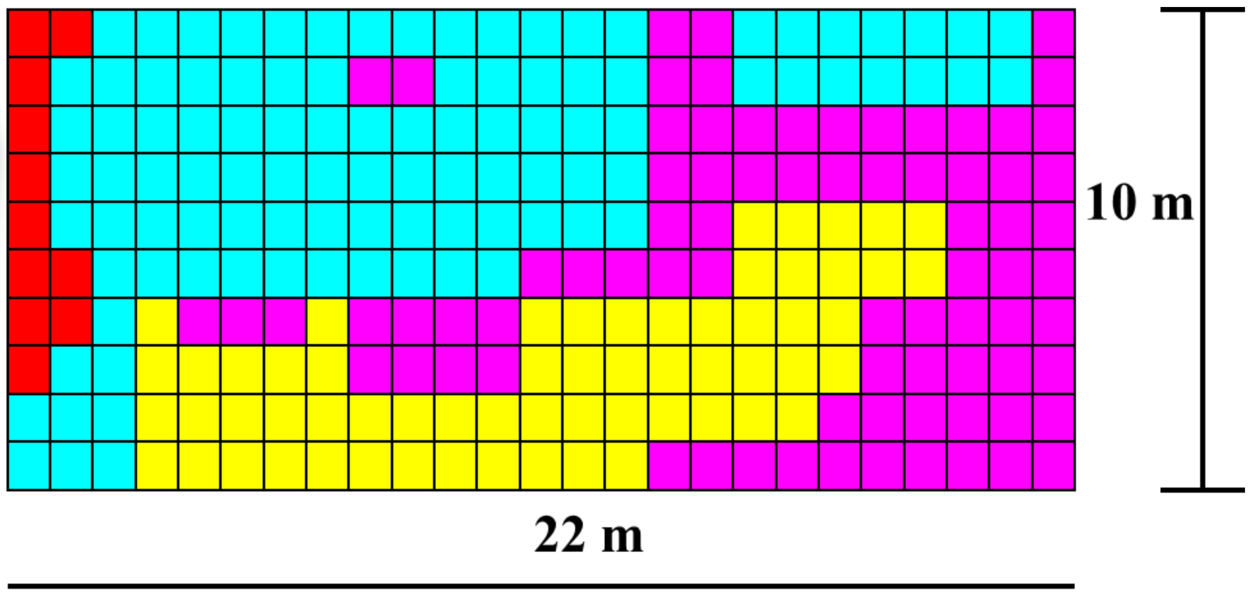
		Hydraulic water head [m]							Thickness [m]
	k-value [m/	0,3	0,5	1	1,5	2	4	8	of GCL / Clay
GCL	1,00E-11	0,27	0,44	0,87	1,30	1,74	3,46	6,92	0,01
GCL	5,00E-11	1,34	2,20	4,36	6,52	8,68	17,32	34,60	0,01
GCL	1,00E-10	2,68	4,41	8,73	13,05	17,37	34,65	69,21	0,01
GCL coated	1,00E-14	0,0003	0,0004	0,0009	0,0013	0,0017	0,0035	0,0069	0,01
Clay	1,00E-08	19,01	25,92	43,20	60,48	77,76	146,88	285,12	0,25
Clay	1,00E-08	13,82	17,28	25,92	34,56	43,20	77,76	146,88	0,5
Clay	1,00E-08	12,10	14,40	20,16	25,92	31,68	54,72	100,80	0,75
Clay	1,00E-08	11,23	12,96	17,28	21,60	25,92	43,20	77,76	1
Clay	5,00E-09	9,50	12,96	21,60	30,24	38,88	73,44	142,56	0,25
Clay	5,00E-09	6,91	8,64	12,96	17,28	21,60	38,88	73,44	0,5
Clay	5,00E-09	6,05	7,20	10,08	12,96	15,84	27,36	50,40	0,75
Clay	5,00E-09	5,62	6,48	8,64	10,80	12,96	21,60	38,88	1
Clay	1,00E-09	1,90	2,59	4,32	6,05	7,78	14,69	28,51	0,25
Clay	1,00E-09	1,38	1,73	2,59	3,46	4,32	7,78	14,69	0,5
Clay	1,00E-09	1,21	1,44	2,02	2,59	3,17	5,47	10,08	0,75
Clay	1,00E-09	1,12	1,30	1,73	2,16	2,59	4,32	7,78	1

The bentonite mass per unit area of the GCL is approx. 4500g/m².

- k-value (permeability) of GCL used for comparison
- calculated permeation through the GCL under the given hydraulic head [0,3 - 1 m]
- GCL performs better (less permeation) than the clay under the specific hydraulic head, k-value and thickness conditions
- Clay performs better (less permeation) than the GCL under the specific hydraulic head, k-value and thickness conditions
- Permeation rate of Bentofix X (coated GCL)

Permeability Variations in a Compacted Clay Liner (Rowgowski, 1986)



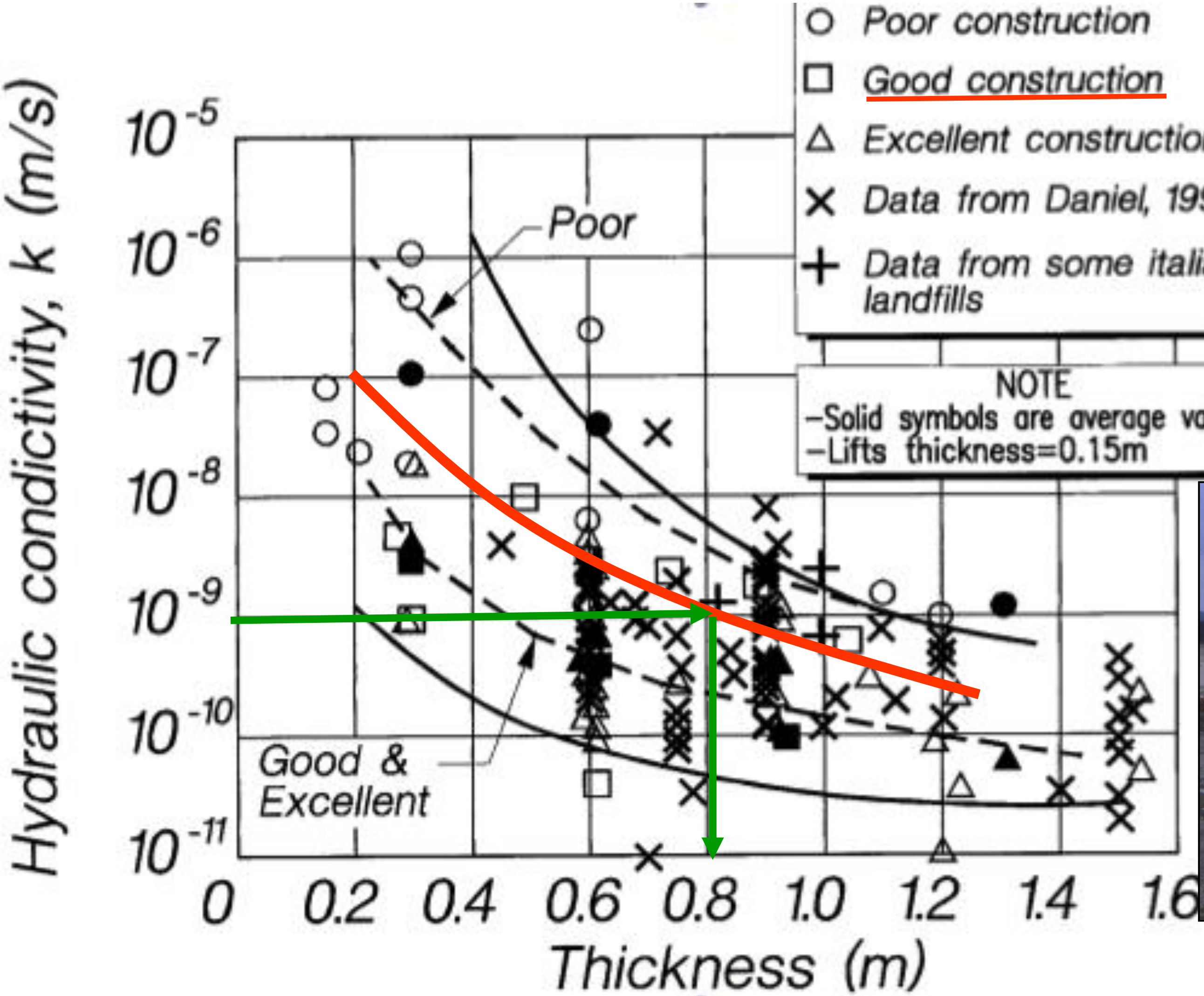


Clay thickness 0.50m / hydraulic water head 0.30m

1 x 10^{-7} m/s (red)	6.08 m³/ha/day
1 x 10^{-8} m/s (cyan)	5.53
1 x 10^{-9} m/s (magenta)	0.43
1 x 10^{-10} m/s (yellow)	0.03
	Total = 12.07

GCLthickness 0.01m / water head 0.30m

1 x 10^{-11} m/s = 0.27 m³/ha/day
5 x 10^{-11} m/s = 1.34 m³/ha/day
1 x 10^{-10} m/s = 2.68 m³/ha/day

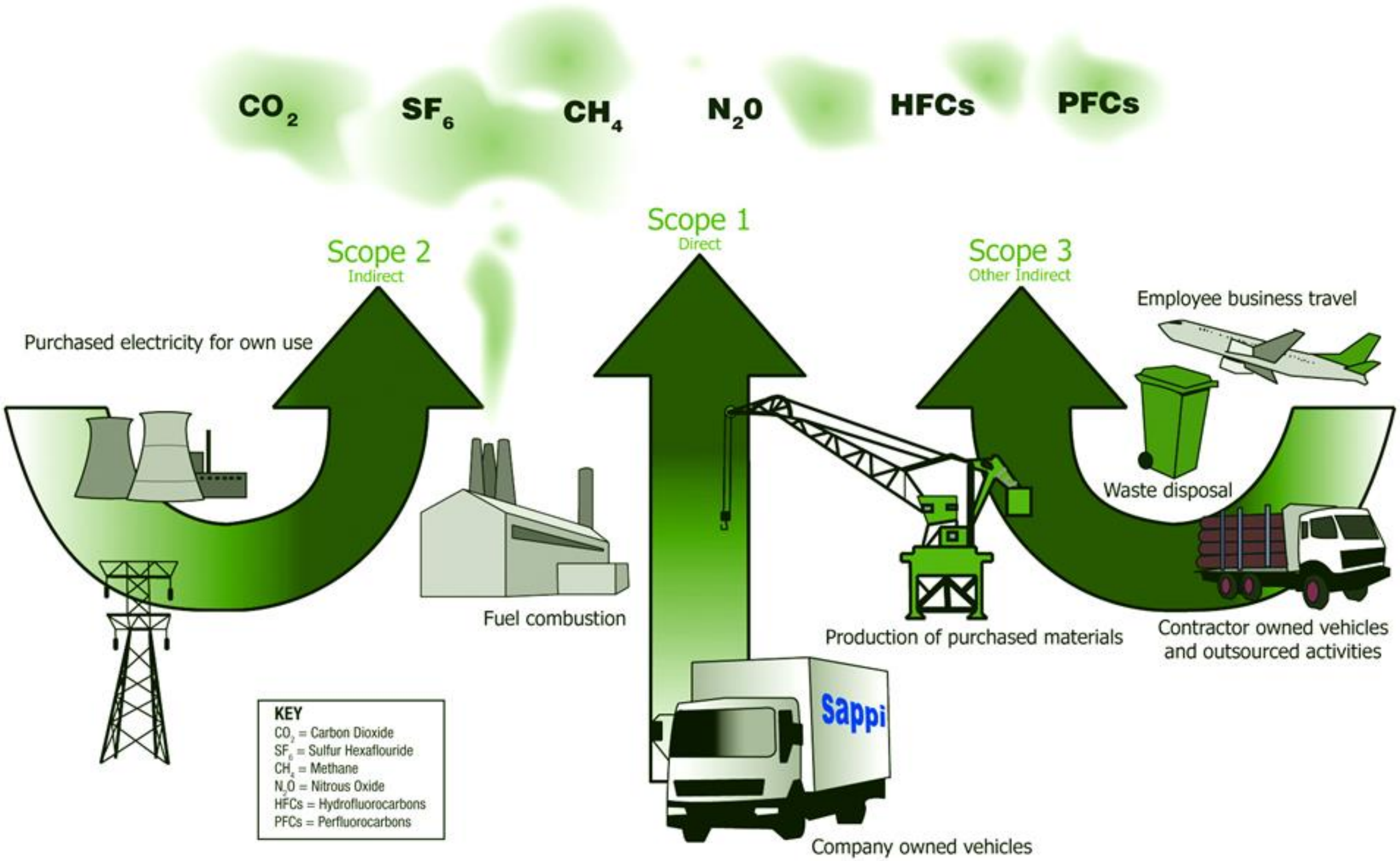


CCL Target:
1 x 10^{-9} m/s

Compacted Clay liners have a high variation based on installation

Carbon Footprint

Carbon footprint can be defined as the total emissions caused by a person, an organization, a product, etc. which is then typically expressed as **carbon dioxide equivalent**.



https://redballoon.in/carbon-footprint/

Sustainability

The main purposes of each sustainable waste management system are to minimize negative ecologic, environmental, social and economic effects, by isolating any type of waste, which is currently unsuitable for a further re-use.
Sustainable landfilling is not a final storage, but is crucial to avoid an environmental impact at any time and at the same time being an economical solution allowing the safe waste storage within a landfill.

https://www.footprintnetwork.org/2017/09/01/making-sustainable-development-goals-consistent-sustainability/

Determinants of liner sustainability in landfills

- Sustainable landfills should be understood as the **safe disposal of waste**.
- They should be built with the **most financially and ecological efficient method**.
- The landfill should cause **minimal damage to the environment**.
- And they should **perform** for a defined (long) period after closure.

Considering compacted clay liners (CCL) and geosynthetic clay liners (GCL) the **long-term** performance of a sustainable landfill liner **has to limit environmental impacts** (release of pollutants to the environment). Technically speaking these three properties are of major interest:

- ***Effect of confining stress***
- ***swell-shrinkage properties and resulting cracking***
- ***hydraulic conductivity in natural conditions***
- ***sustain a long-term hydraulic conductivity even after cyclic changes of saturation***

The Environmental Product Declaration (EPD) communicates verified, transparent and comparable information about the life-cycle environmental impact of products.

Product			Construction		Use	End-of-life			
Raw material	Upstream transport (to production site)	Manufacturing	Downstream transport (to construction site)	Construction and installation	Use	Deconstruction	Transport to the product's waste processing	Waste processing for re-use, recovery	Disposal
A1	A2	A3	A4	A5	B1-B5	C1	C2	C3	C4
x	x	x	x	x	n.a.	n.a.	n.a.	n.a.	n.a.

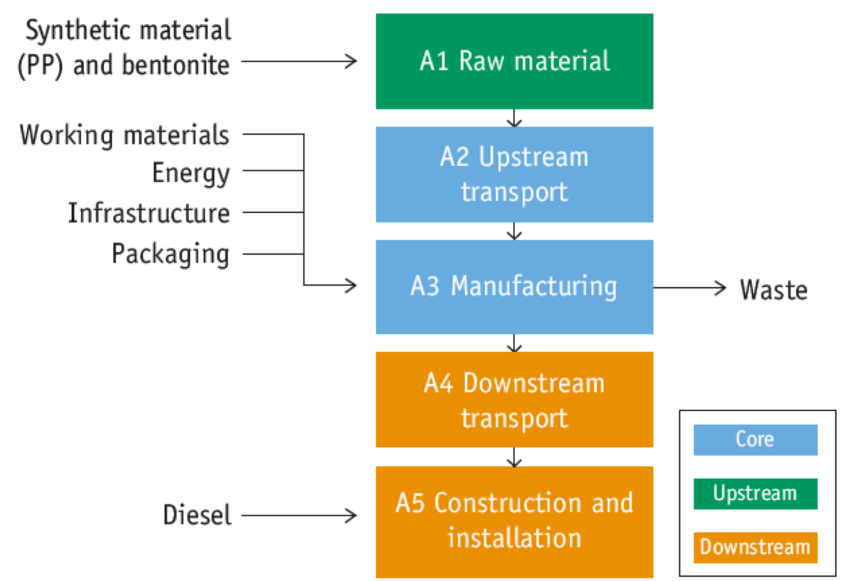


Figure 3
Graphical overview of the life cycle stages covered by the EPD of geosynthetics

Relative contribution of the different life cycle stages to the total impact of a specific Geosynthetic Clay Liner

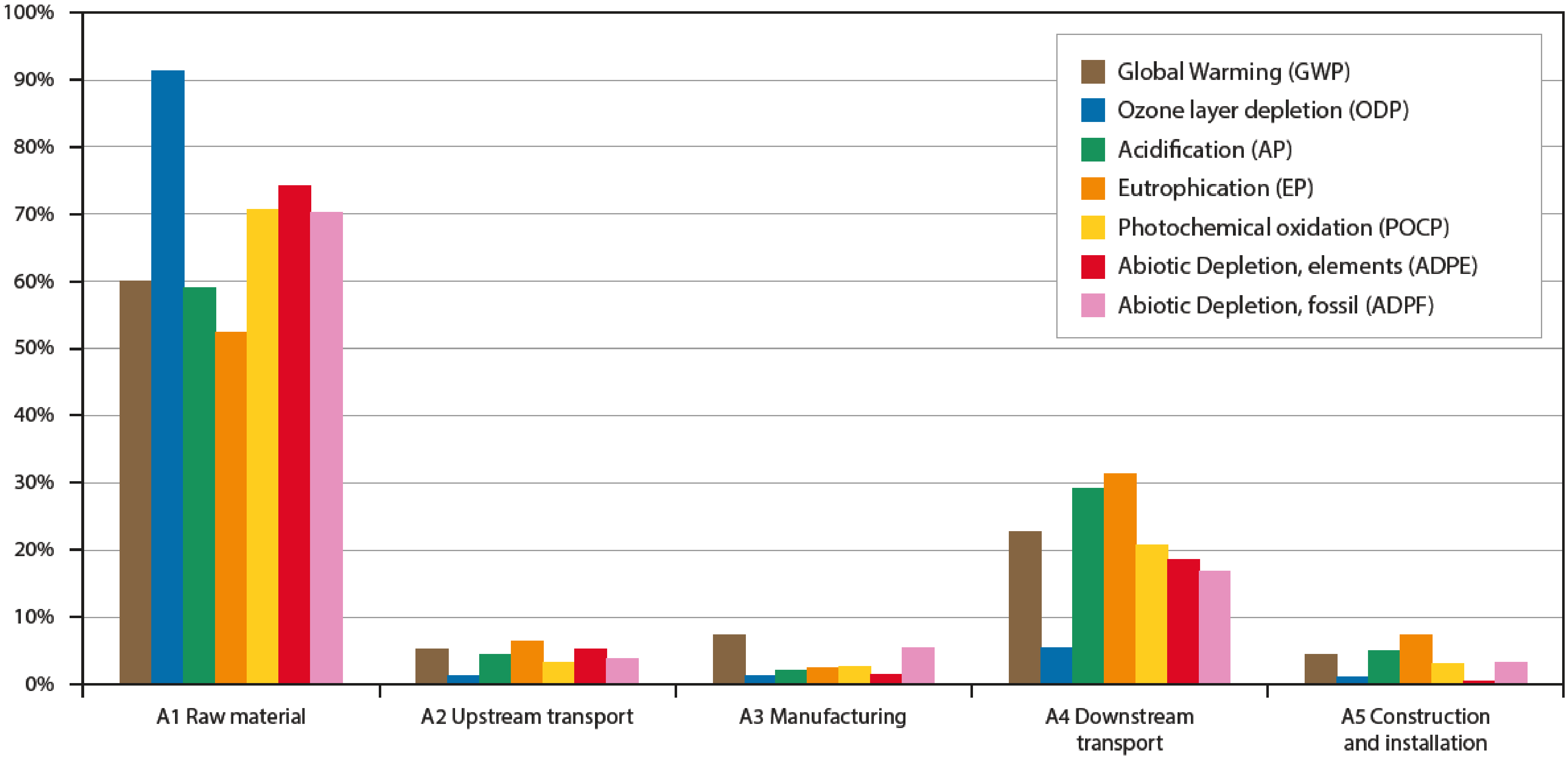


Figure 7

Relative contribution of the different life cycle stages to the total impact of the averaged Bentofix®

Example:

4,500m² sealing with GCL

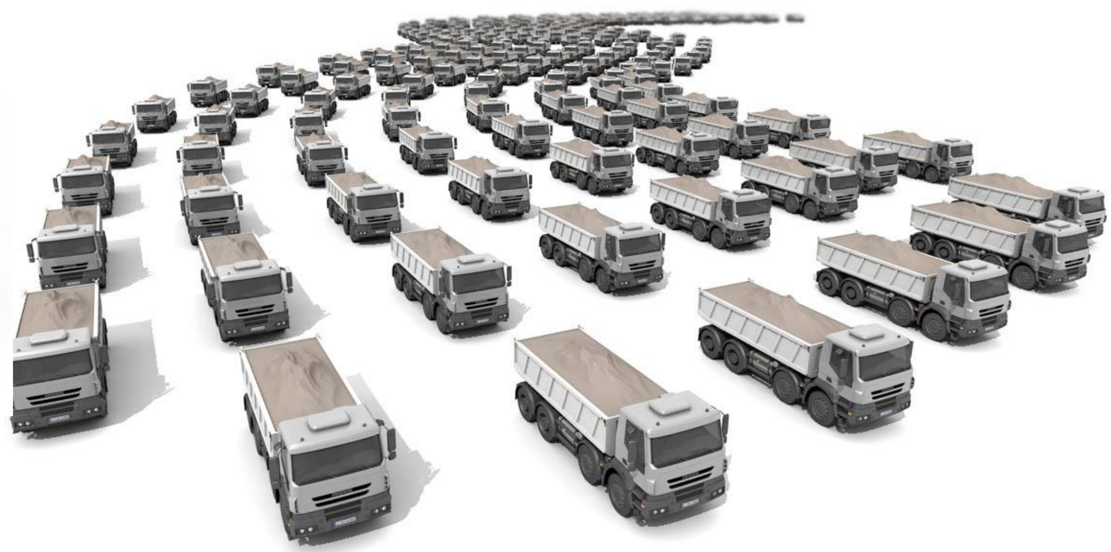
4,500m² sealing with compacted clay (CCL) (500mm thick)

Equals:

Equals:

1 truck

187 trucks



Keep in mind: Road stresses (results in earlier road repair) and noise pollution.

First Basic Energy Consumption Calculations in 1998

Comparison of the energy consumption of a GCL and a CCL [kWh/m²]

	GCL [kW/m²]	CCL [kW/m²]
Production	1.26	
Mining		0,655
Transport	0,518	9,533
Installation	1.077	6,187
Total	2,855	16,375

Without any basic guides it was difficult to compare products or systems with each other but with an equal base-line the trend in favour of geosynthetics was clear

GCL – Geosynthetic Clay Liner

CCL – Compacted Clay Liner

Comparing Life Cycle Assessments (LCA)

…analyse the whole life cycle („product line“) of a product (mining and processing of raw materials, production, distribution and transport, usage, consumption und disposal),

…analyse the ecological effects and evaluate the material and energy volumes occurring during the life cycle and the resulting environmental stress.

Constituent parts of an Live cycle assessment (DIN EN ISO 14040/14044, 2006) and definition of the term Environmental balance

Cumulated energy demand (CED) in Life cycle assessment (LCA)

The multiplicity of environmental effects in Life cycle assessments leads to a huge effort at data collection and complex methods at data evaluation.

If most of the environmental effects result from the resourcing of the energy or the energy usage, the CED can be used as a first rough check, an abbreviated version of the LCA. It provides at least an informative basis for the ecological analysis.

CED is an indicator for a primary rough evaluation of energy for extraction, production, transport and installation of materials. For the following exact CED one also needs further data, however, these can be easily determined and can also be standardised.

Cumulated energy demand (CED)

Balance requirements for comparative product balances

- equal utilisation range
- equal technical state of the art
- equal functional range

Balance factors

1. Mining of raw materials (e.g. soil, bentonite, crude oil)
2. Raw material transportation to the construction site, resp. manufacturer
3. Manufacture of pre-products (e.g. bentonite, PP-granules)
4. Transportation of pre-products to the manufacturer or to the construction site
5. Final product manufacturing (e.g. GBR-C/GCL)
6. Product transportation to the construction site
7. Product installation (e.g. distribution, compaction, installation)

Balance dimension

As balance dimension the Cumulated energy demand (CED) was selected with the unit:

- MJ/kg based on the product resp.
- MJ/m³ compacted/stabilised soil resp.
- GJ for the complete project

Representative for the environmental effects the CO_2-emission in kg per kg resp. m³ or in Mg resp. tons were selected with regard to the greenhouse potential.

4. Cumulated Energy Demand (CED) for a Compacted Clay Liner (CCL)

Processing of Clay and site transportation

Subgrade preparation and clay spreading

Watering, Sheep-foot compacting, levelling, smooth compacting (typical for two layers)

4. Cumulated Energy Demand (CED) for a Compacted Clay Liner (CCL)

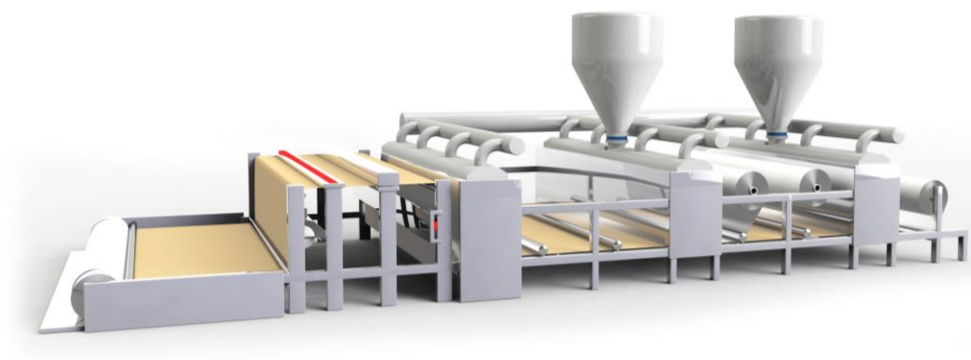
	Data /	Units	Data /	Units	Data /	Units	CED [MJ]	CO_2 [kg]
Surface sealed:	36000	m²						
Mineral sealing with a medium thickness of 62,5 cm	22500	m³						
Soil extraction - covering with shovel excavator	22500	m³			7.6	MJ/m³	171000	13856
Soil transport 45000 t, Transport distance:	35	km	45000	t	2.5	MJ/tkm	3937500	319056
Installation with the caterpillar tractor in 2 to 3 layers of 0,25 - 0,33 m thickness	22500	m³			8.98	MJ/m³	202050	16372
Compacting using a soil compactor in 2 - 3 layers of 0,5 - 0,33 m thickness	22500	m³			4.14	MJ/m³	93150	7548
Total of cumulated energy demand (CED) [MJ] / Total CO2 [kg]							4403700	356832
CED [MJ/m²] / CO2 [kg/m²]							122.3	9.9

Table 2. Soil cover for sealing layers (CCL)

	Daten	[Einh.]	Daten	[Einh.]	Daten	[Einh.]	CED [MJ]	CO_2 [kg]
Soil extraction - covering with shovel excavator	36000	m³			7.6	MJ/m³	273600	22170
Soil transport 57600 t, transport distance:	20	km	57600	t	2.5	MJ/tkm	2880000	233366
Installation with the caterpillar tractor in 2 layers of 0,40 m thickness	28800	m³			8.98	MJ/m³	258624	20956
Installation of top soil cover with the long-arm excavator d = 0.2 m	7200	m³			1.97	MJ/m³	14156	1147
Total of cumulated energy demand (CED) [MJ] / Total CO2 [kg]							3426380	277639
CED [MJ/m²] / CO2 [kg/m²]							95.2	7.7
CED [MJ/m²] / CO2 [kg/m²] for CCL and cover							**217.5**	**17.6**

4. Cumulated Energy Demand (CED) for a Geosynthetic Clay Liner (GCL)

Raw material mining/production and transportation



GCL production

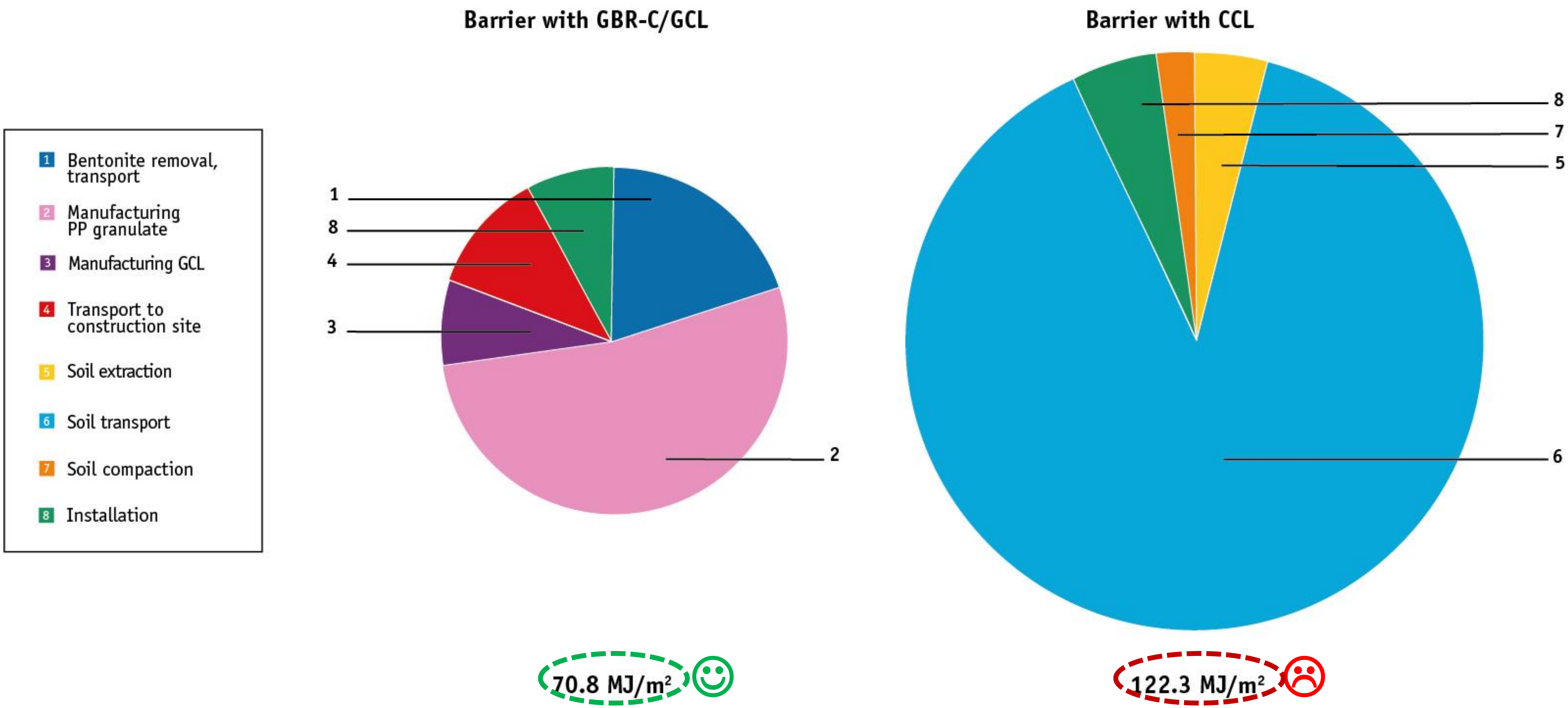
GCL transportation to site

GCL installation

4. Cumulated Energy Demand (CED) for a Geosynthetic Clay Liner (GCL)

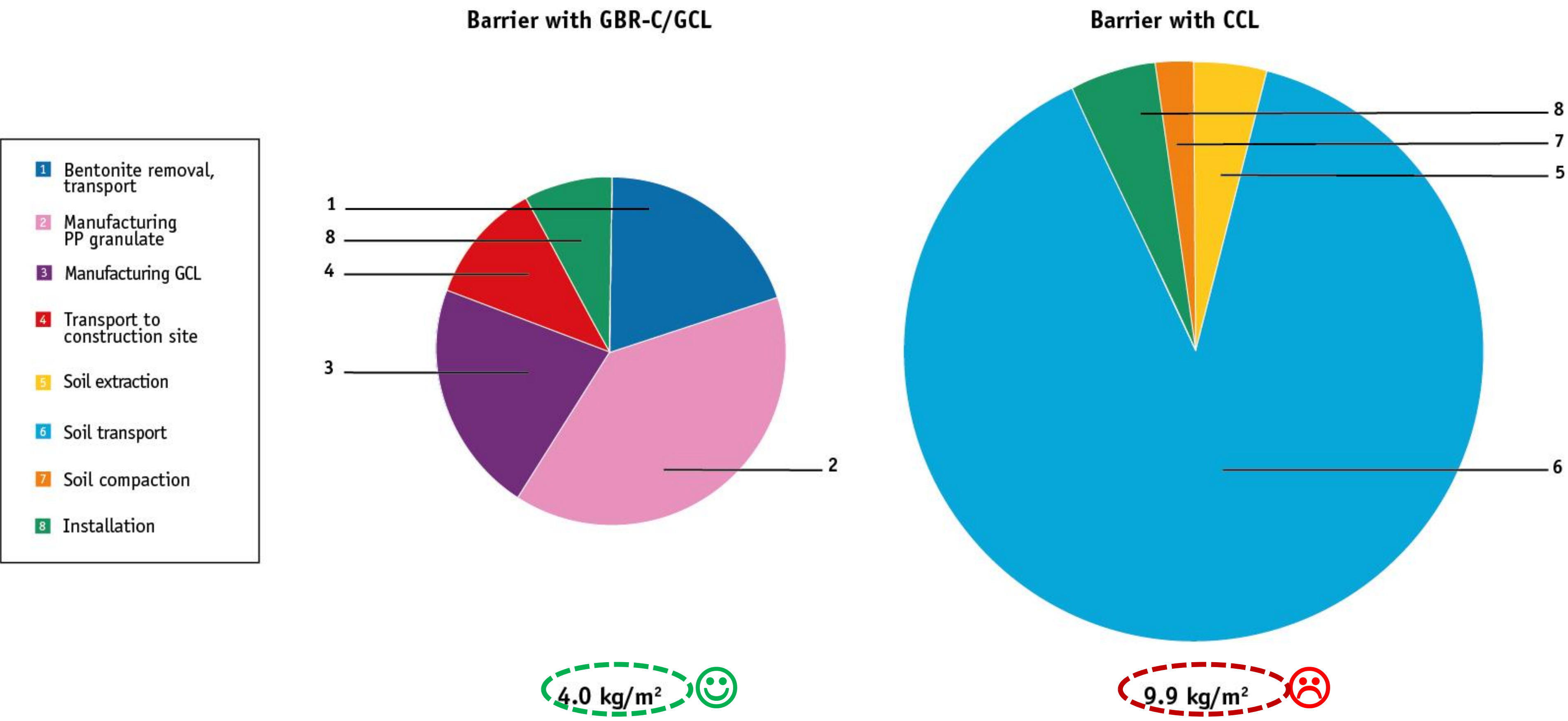
	Data / Units	Data / Units	Data / Units	CED [MJ]	CO_2 [kg]
Sealed surface (GCL measurements 45 x 4,8 m per roll) GCL Bentofix B 4000 installed, surface weight 5.35 kg/m² incl. 6.2 %overlapping (30 cm with a 4,85 m mat width)	36000 m² 5.68 kg/m²				
Bentonite, removal, transport to the manufacturer Naue Amount of bentonite per square meter 4,7 kg/m² incl. 6.2% overlapping (30 cm with 4.85 mat width)	4.99 kg/m²	179666 kg	2.46 MJ/kg	441978	28747
Primary energy content (Feedstock): **Manufacture** of polypropylene granulate:	0.69 kg/m²	24840 kg	47.50 MJ/kg 65.50 MJ/kg	1627020	56635
Manufacture of polypropylene geomembrane and material combination (suface weight 650 g/m² incl. overlapping)	0.69 kg/m²		3.6 MJ/kg	89451	16623
Manufacture of GCL	5.68 kg/m²		2.196 MJ/m²	79056	14691
Transport to the construction site, distance to the manufactures´s plant in Espelkamp	580 km	204.5 t	1.75 MJ/tkm	207581	16820
Installation of GCL with excavator and whee loader	36000 m²		3.887 MJ/m²	139932	11339
Total of cumulated energy demand (CED) [MJ] / Total CO2 [kg]				2585018	144855
CED [MJ/m²] / CO2 [kg/m²]				71.8	4.0

Comparison of energy demand [mJ/m²] – 36,000 m²



Installation of a GCL results in 42 % less energy demand than a CCL!

Comparison of CO_2 emissions – 36,000 m²



Installation of a GCL results in 59 % less CO_2 emmissions than a CCL!

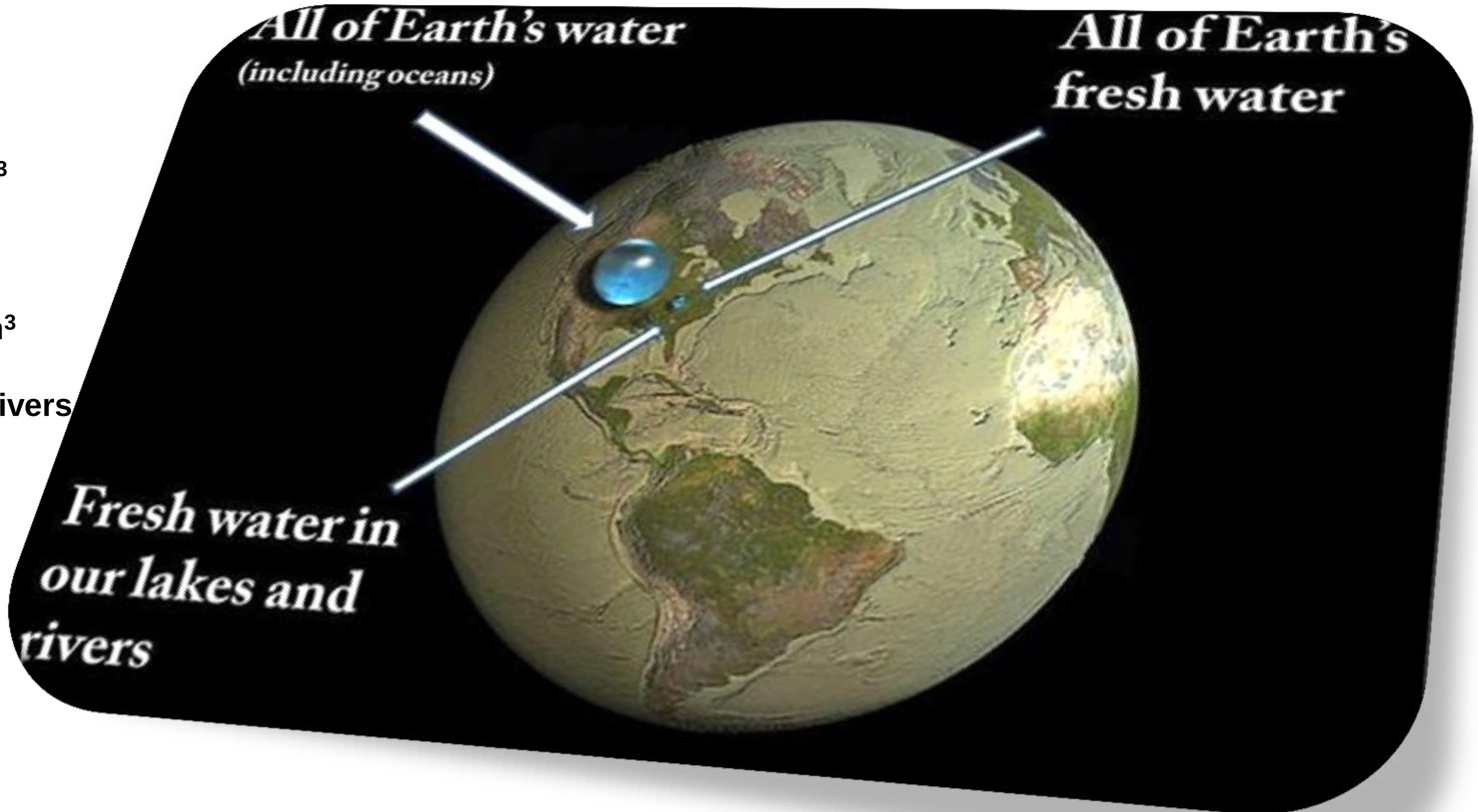
Do you know how much (correction: little) fresh water there is on Earth?
If total water is 100% - what percentage is salt water and what percentage is fresh?
The U.S. Geological Survey (USGS) has created an infographic that concentrates all of the planet's fresh water in one (tiny) area - see below. NOTE: Approximately 80% of 'all of Earth's fresh water' is unavailable to us - it's stored (frozen) in the World's icecaps and glaciers. That's why we set-up the Water Summit - we see an urgent need for collaboration, creative problem solving and strategic thinking in the Water Sector.

Largest Sphere - Total
Diameter ≈ 1 380 km
Volume ≈ 1,39 billion km^3

Smaller Sphere - Fresh
Diameter ≈ 273 km
Volume ≈ 10,6 million km^3

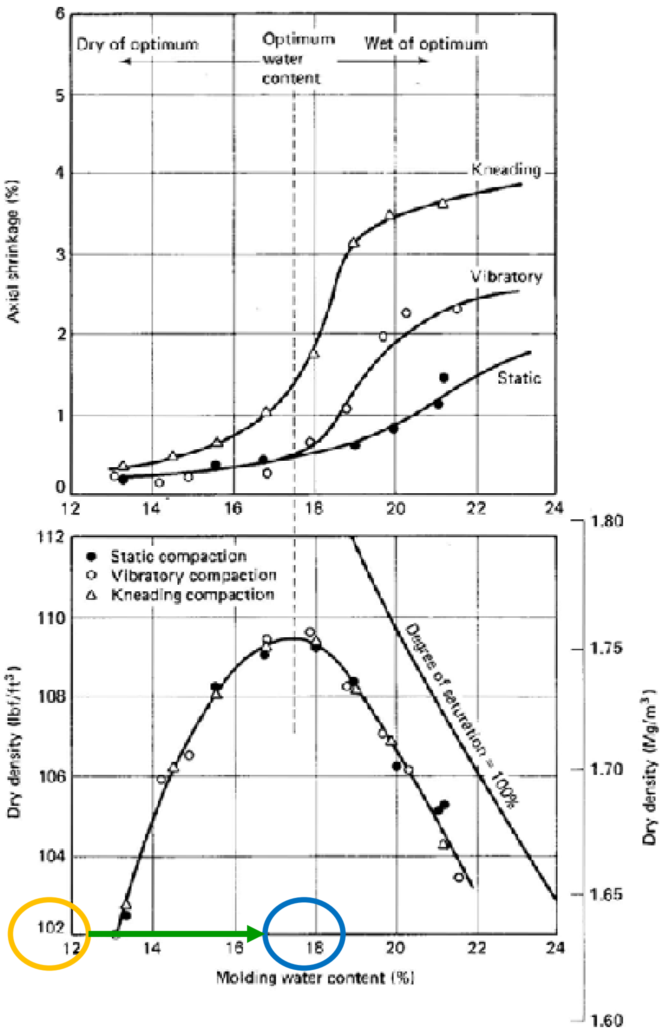
Tiny Sphere – Lakes & Rivers
Diameter ≈ 56 km
Volume ≈ 93 000 km^3

(USGS, 2016)



Tonkin + Taylor:
https://www.linkedin.com/company/1314128/?lipi=urn%3Ali%3Apage%3Ad_flagship3_company%3B5HK%2BK4RhRAmGb%2F9cLnG7GQ%3D%3D&licu=urn%3Ali%3Acontrol%3Ad_flagship3_company-actor

How much water is needed for a compacted clay liner?



Area: 40,000m² - Clay thickness: 0.5m
Need to add approx. 1,500,000 l of water

What is the minimum quantity of water needed?
20 litres per capita per day (over 200 capita/year!)

Landfill Caps with a GCL

1. Reduction of energy demand and CO_2 emmisions in construction is required.

2. Geosynthetics, such as GCLs are suitable solutions.

3. During production the synthetic and bentonite component has the highest CED and CO_2 emission, but in total still far less than that of a CCL.

4. For compacted clay (CCL) the main influencing factor of energy demand and CO_2 emisions is its volume and transportation.

5. The intelligent usage of geosynthetics in geotechnics and in civil engineering offers next to the cost advantages also ecological advantages for the environment.

Final Statement: However, these statements cannot be generalised. It is always necessary to generate application specific analyses.

Questions are welcome.

Thank you for your interest.

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