Special print

Comparative life cycle assessment (LCA) for clay geosynthetic barriers (GBR-C / GCL) versus compacted clay liners and other sealing systems used in river dykes, canals, storm water retention ponds and landfills

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ABSTRACT

Since CO_2-emission is accepted as one factor for climate warming and CO_2 certificates are being used for trade, ecological balances for product selections are getting more and more important, especially in terms of economical and political views and are considered as hard facts for product decisions. In the meantime, countries are starting to establish comparable selection criteria for construction materials and methods, so that the cumulated energy consumption and CO_2 emissions can be compared with each other. Geosynthetic Clay Liners (GCLs), also known as Geosynthetic Clay Barriers (GBR-C) are composite products manufactured from two high-quality, relatively energy-consuming basic materials, one is usually polypropylene, a high-grade and energy-intensive geosynthetic and the other bentonite, a high-quality clay usually transported over long distances. Neither actually have good prerequisites for a favourable eco-balance. However, compared to compacted clay lines (CCL), GCLs compare very well and perform with a much lower energy balance and CO_2 emission, mainly due to the low mass per unit area of all components (approx. 4 - 5 kg/m^2). A main influencing factor for the high energy consumption with clay liners is the volume of clay (approx. 1,000 kg/m^2 at a thickness of 0.5 m!) that needs to be excavated, transported to the site, distributed and compacted. Compared to that, GCLs can be transported over long distances (approx. 4.500 m^2/truck load) without a great influence on the energy balance. In addition the installation of GCLs needs only relatively light equipment.

1. INTRODUCTION

A Life Cycle Assessment (LCA) denotes the systematic analysis of the environmental impact of products during their entire life cycle (extraction and treatment of raw materials, production, distribution and transport, use, consumption and disposal). This comprises any environmental impact during the production, utilization phase and disposal of the product as well as the upstream and downstream processes connected to that (e.g. production of raw and process materials). Environmental impact may include any ecologically relevant extraction from the environment (e.g. raw oil, soil, ore) as well as emission into the environment (e.g. waste, carbon dioxide emissions).

A distinction is generally made between:
- a life cycle assessment taking into account the environmental impact of an individual product,
- a comparative life cycle assessment pursuing a confrontation of several products, as well as
- an integral account, embracing the economical, technical and / or social aspects.

Figure 1 shows the phases of a life cycle assessment and the correlation between the terms life cycle inventory analysis, impact balance or impact assessment, respectively, and evaluation. Direct applications of life cycle assessments comprise for instance the development and improvement of products, strategic planning, political decision making processes or marketing etc.

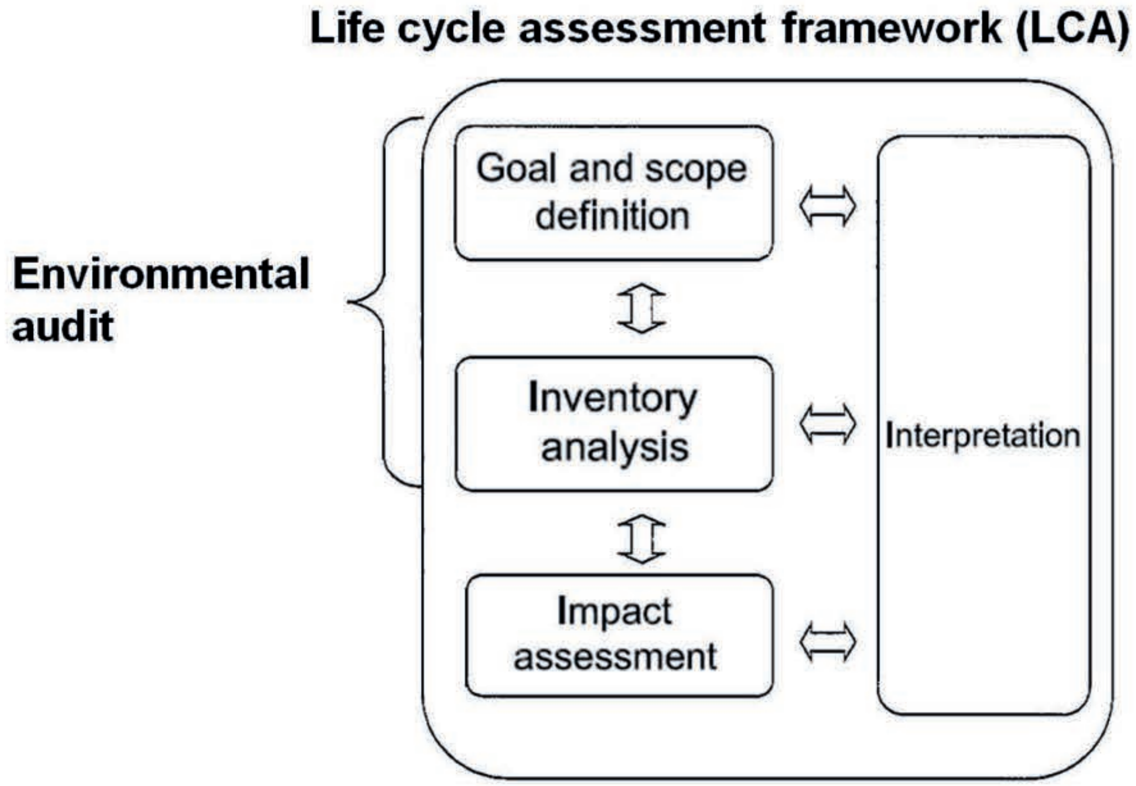


Figure 1. Constituents of a life cycle assessment (pursuant to EN ISO 14040 2006-10 and 14044 2006-10) and definition of the term environmental audit.

2. EXPLANATIONS CONCERNING LIFE CYCLE ASSESSMENT, INVENTORY ANALYSIS AND IMPACT BALANCE, SCOPE OF ASSESSMENT AND CUMULATED ENERGY DEMAND (CED)

The procedure of an LCA can be divided into four steps:

a) Determination of the objective and scope of assessment (scoping)
Determination of the framework, identification of the scope of assessment (planning target), justification of the priority setting, determination of balance scope and balance criteria
b) Life cycle inventory analysis – account of the material and energy flows
c) Impact analysis and evaluation including the determination of environmental goals of overriding importance
d) Optimisation

2.1 Method for the compilation of an impact balance

In the interest of a subsequent, possibly comprehensive evaluation it is reasonable to conduct an impact related account between the sole life cycle inventory analysis and the evaluation of the balance. The flow and inventory parameters collected in the life cycle inventory analysis are described or assessed, respectively, with regard to their potential effects. Their impact on selected global and regional or local environmental factors is considered. The effects from the life cycle inventory analysis may be analysed with regard to the following environmental categories (SETAC 1993):

- Resource depletion,
- Land use,
- Global warming,
- Ozone depletion,
- Photochemical ozone creation,
- Acidification,

- Eutrophication, nutrification,
- Toxicological effects,
- Ecotoxicological effects,
- Waste, and
- Modification of ecosystems and landscapes.

Prerequisites for comparative product balances:

- same scope of use,
- same state-of-the-art technology,
- same range of functions,

2.2 Balance factors

The comparison is conducted by means of the following balance factors:

- Extraction of raw materials (e.g. soil, sand, gravel, limestone, marl, clay, iron ore, crude oil),
- Transport of the raw materials to the site or the manufacturer,
- Production of the primary products (e.g. cement, lime, structural steel, PP granulate),
- Transport of the primary products to the manufacturer or the construction site,
- Manufacturing of the products (e.g. concrete, geogrid, geotextiles),
- Transport of the products to the construction site, and
- Integration of the products (e.g. distribution, milling, consolidation, laying).

2.3 Balance dimensions

The cumulated energy demand (CED) is stated with the units:

- MJ/kg in relation to the product, or
- MJ/m³ in relation to the compacted / stabilised soil, or
- MJ/m² in relation to the compacted / sealed surface.

As a representative for the environmental impact, the CO_2 emissions are indicated in kg per kg of the applied product or in kg per m³ of stabilised soil or in kg per m² of sealed area with regard to the global warming potential.

2.4 CED (cumulated energy demand) in life cycle assessments

The multitude of environmental impacts leads to a complexity in the data collection process and to complex methods for evaluation.

If a large part of the environmental effects results from the provision and consumption of energy, the CED may be used as a first rough check “Short life cycle assessment” in many cases. It provides at least first clues with regard to an ecological evaluation.

The CED is a first indicator for a rough first evaluation of the energy, transport and material services. Even though the CED also requires data; the energy data may be collected and standardised easily (UBA 1999).

3. EXTRACTION AND MANUFACTURE OF CONSTRUCTION MATERIALS

3.1 Geosynthetic Clay Liner (GCL)

Carrier and cover layers (polypropylene woven and nonwoven)

Carrier and cover layers made of polypropylene are the subject of the investigation carried out here concerning the surface sealing for the Kinzig dykes (see below) using the GCL (650 g/m²). For calculating the CED and using information of the FFE (1999) regarding the manufacture of PP granulate material (65.5 MJ/kg), the manufacture of PP fibres (1.908 MJ/kg) and the manufacture of polypropylene geomembrane material (0.324 MJ/kg), data in an earlier publication (Egloffstein and Burkhardt 2005) were drawn upon, which were based on manufacturers' details. The same applies for the manufacture of polypropylene geomembrane material and material combination (3.6 MJ/kg) of a GCL as well as the CED for their production (2.196 MJ/m^2).

Bentonite

The cumulated energy demand for the extraction, preparation (usually drying) and the transport of Wyoming bentonite by ocean-going ships, inland shipping and lorries to the manufacturer has been described in detail by Egloffstein and Burkhardt (1998). For the investigation carried out here, a cumulated energy demand of 2.46 MJ/kg and a CO_2 emission of 160 g per kg bentonite were taken over from FEE (1999).

3.2 Soil as a sealing liner

The cumulated energy demand in constructions with soil as a building material consists of energy consumption from removal, transport and installation. Unlike geosynthetics, soil has no energy content (feedstock). The CO_2 emission is correspondingly linked directly with the diesel consumption of the construction equipment and lorry. Constructions from soil usually have a large mass, whose extraction (excavator), transport (lorry) and installation (usually pushed with a bulldozer and compacted layer by layer with a soil compactor) have a high energy consumption. Decisively important for the direct ecological comparison is, however, the transport distance of these soil masses, where in a comparison between a geosynthetic clay liner and a soil liner the pendulum can, according to the transport distance for the soil liner (CED ca. 2.5 MJ/tkm), swing to the one or the other alternative. This means that if the soil is already at the site or if the soil extraction site is very near the construction site, then mineral sealing can be ecologically more favourable. If the sealing material has to be transported over greater distances, then the bentonite mat has ecological advantages. The transport distance for geosynthetic clay sealing from the manufacturing plant to the construction site is, in contrast, because of the comparatively low mass, of negligible significance.

4. LOADING, TRANSPORT, INTEGRATION

Transport processes for construction materials naturally also play an important role when it comes to the ecological comparison of the construction materials and systems. Per transport ton kilometre (tkm) by lorry, an energy consumption between approx. 1.2 and 3.4 MJ/tkm can be estimated, depending on the size of the lorry (e.g. Euro trailer) and the ratio between short and long-haul traffic. A CO_2 emission of 120 to 350 g/tkm is directly linked to this. Based on the production site for the GCL considered here in Espelkamp, the transport distance to the construction site is statistically and naturally always greater than to the regionally more widespread clay material for sealing purposes. In relation to the entire Federal Republic of Germany, the products of the above-mentioned producer have, statistically speaking, an average one-way transport distance in the range of approx. 350 km. On average and concerning the Federal Republic of Germany, the soil supply will be located even closer to the site. However, it is at times surprising how far soil is sometimes transported solely on the basis of price differences and distortion of competition. The transport distances for geosynthetics, which are on average considerably higher, are generally more than counterbalanced by the considerably lower tonnages required for geosynthetics. As a reminder, the above-mentioned comparison is referred to again: 5.35 kg of the GCL (respectively GBR-C) per square meter compared to 1000 kg per square meter of soil if the sealing layer has a thickness of 50 cm. Accordingly, the loading and installation of GCLs requires only light tracked devices (fork-lift truck, wheeled loader) or may be conducted on site with a excavator-wheeled loader-unit and comparatively light equipment compared to earthworks or special civil engineering works. For detailed data with regard to the approaches considering transport distance, excavation of soil and installation of the materials please refer to Table 1 to 3.

5. COMPARISON OF AN EXTERNAL SEALING FOR A RIVER DYKE ON THE KINZIG USING A GCL AND A MINERAL SEALING (CCL) ACCORDING TO THE DWA LEAFLET "SEALING SYSTEMS IN DYKES"

The comparison of an external sealing for a river dyke using a geosynthetic clay sealing liner with a mineral sealing with an average thickness of 0.625 m also turns out in favour of the geosynthetic clay sealing liner (CED = 71.8 to 122.3 MJ/m^2). The difference in the cumulated energy demand of the two sealing systems is, however, comparatively insignificant. A medium transport distance of 35 km (one-way) was assumed for the mineral sealing material, which makes up a lion's share of the CED for the required sealing material of 45.000 tons. For the bentonite mat the main share in the CED is the polypropylene, which at a surface weight of 0.69 kg/m^2 PP (incl. 6.2% overlapping) is a major factor. When comparing the two sealing systems, the transport distance for the mineral sealing material is the decisive parameter. If the place of extraction is on-site or very near to the place of installation, then the mineral sealing - mostly because it has no energy content (feedstock) - can hardly be beaten. In the case of the bentonite mat, the main part of the CED is the energy content (feedstock) of the polypropylene (ca. 53%). The transport distance for the GCLs from the manufacturer's plant in Espelkamp to Offenburg (580 km) is, in comparison as regards the CED compared to the PP granulate material, of hardly decisive consequence (ca. 8.5%).

The covering soil which has to be put in position as weather protection for both sealing methods (here: d = 0.8 m), is at 97 MJ/m^2 with an assumed average transport distance of 20 km for both surface sealing systems, in particular when comparing these systems with other systems (see Chap. 5.4), of quite considerable consequence. The distribution concerning environmentally relevant CO_2 corresponds approximately to the CED, the bentonite mat has a CO_2 emission of 4.0 kg/m², the mineral sealing of 9.9 kg/m² and the covering soil is entered in the CO_2 balance sheet with 7.9 kg/m^2.

Table 1. Dyke sealing – Rehabilitation of the Kinzig dykes with GCL-C

	Data / Units	Data /Units	Data / Units	CED [MJ]	CO_2 [kg]
(Example DWA Leaflet "Sealing Systems in Dykes" Sealed surface mat measurements 45 x 4,8 m	36000 m^3				
GCL Bentofix B 4000 installed, surface weight 5.35 kg/m² incl. 6.2 %overlapping (30 cm with a 4,85 m mat width)	5.68 kg/m^2				
Bentonite, removal, transport to the manufacturer Naue Amount of bentonite per square meter 4,7 kg/m^2 incl. 6.2% overlapping (30 cm with 4.85 mat width)	4.99 kg/m^2	179666 kg	2.46 MJ/kg	441978	28747
Primary energy content (Feedstock):			47.50 MJ/kg		
Manufacture of polypropylene granulate:	0.69 kg/m²	24840 kg	65.50 MJ/kg	1627020	56635
Manufacture of polypropylene geomembrane and material combination (surface 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 manufacturer's plant in Espelkamp	580 km	204.5 t	1.75 MJ/tkm	207581	16820
Installation of GCL with excavator and wheel loader	36000 m^2		3.887 MJ/m^2	139932	11339

	Data / Units	Data /Units	Data / Units	CED [MJ]	CO_2 [kg]
Total of cumulated energy demand (CED) [MJ]/Total CO_2 [t]				2585018	144855
CED [MJ/m^2] / CO_2 [kg/m^2]				71.8	4.0

Table 2. Dyke sealing – Rehabilitation of the Kinzig dykes with compacted clay liners (CCL)

	Data /Units	Data / Units	Data / Units	CED [MJ]	CO_2 [kg]
(Example: DWA Leaflet "Sealing systems in dykes"					
Surface sealed:	36000 m^2				
Mineral sealing with a medium thickness of 62,5 cm	22500 m^3				
Soil extraction - covering with shovel excavator	22500 m^3		7.6 MJ/m^3	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 m^3		8.98 MJ/m^3	202050	16372
Compacting using a soil compactor in 2 - 3 layers of 0,5 - 0,33 m thickness	22500 m^3		4.14 MJ/m^3	93150	7548
Total CED [MJ] / Total CO_2 [kg]				4403700	356832
CED [MJ/m^2] / CO_2 [kg/m^2]				122.3	9.9

Table 3. Soil cover for sealing layers (GCL or CCL)

	Data	/ Units	Data	/ Units	Data	/ Units	CED [MJ]	CO_2 [kg]
Soil extraction - covering with shovel excavator	36000	m^3			7.6	MJ/m^3	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	m^3			8.98	MJ/m^3	258624	20956
Soil compacting using a soil compactor in 2 layers of 0,40 m thickness	28800	m^3			3.195	MJ/m^3	92016	7456
Installation of top soil cover with the long-arm excavator d = 0,2 m	7200	m^3			1.97	MJ/m^3	14156	1147
Total CED [MJ] / CO_2 [kg]							3518396	285096
CED [MJ/m^2]/ CO2 [kg/m^2]							97.7	7.9
CED [MJ/m^2] / CO_2 [kg/m^2] for GCL sealing and cover							169.5	11.9
CED [MJ/m^2] / CO_2 [kg/m^2]for CCL and cover							220.1	17.8

6. SUMMARY

Polypropylene is a high-quality material with a high to very high CED (Cumulated Energy Demand) and a high emission of CO_2 and other pollution gases. Therefore, for ecological and economic reasons it should, as far as possible, only be used in an intelligent and economical manner. This is usually the case with geosynthetics, which are only used in very low specific amounts (GCL: 5.35 kg/m^2, bentonite 4.7 kg/m^2, PP 0.65 kg/m^2). Bentonite also is a very high-quality mineral material with distinctly lower but nevertheless not inconsiderable energy consumption and a thus associated CO_2 emission for removal, drying and transport of bentonite in this case from Wyoming or other bentonites from around the world to Germany.

Loading, transport and installation processes are in the case of geosynthetics, because of the lower quantities and the lower specific weight, of far less consequence than in the case of the required large masses of soil.

Geosynthetics have a high energy content which is included in the cumulated energy demand (CED) (polypropylene and polyethylene approx. 47 MJ/kg) in the form of the calorific value (feedstock). For this type of direct comparison with materials and products without feedstock (soil, concrete, steel) or with a negligibly low feedstock (hydration heat of lime and cement) this is an essential (but according to general opinion unchangeable) disadvantage.

Thus a comparison between e.g. a mineral soil sealing (without feedstock) from soil situated at the site or which can be obtained not too far away from the site, can, in spite of the higher mass around the factor ± 200, not least because of the comparatively high feedstock amount of a GCL, come off more favourably regarding a cumulated energy demand and CO_2 emissions than a geosynthetic clay sealing liner (compare the results CED /CO_2 of Table 1 and 2). This advantage depends entirely on the transport distance of the sealing soil. As soon as this had to be transported over greater distances, the geosynthetic clay sealing liner clearly has the advantage because of its lower weight.

Consequently, the intelligent use of geosynthetics in geotechnics and in civil engineering not only offers cost advantages but generally also ecological advantages for the environment. However, this statement cannot be generalized and has to be considered individually for each application and product.

7. REFERENCES AND FURTHER LITERATURE REGARDING THE SUBJECT

EN ISO 14040 (2006). *Umweltmanagement – Ökobilanz – Grundsätze und Rahmenbedingungen; Environmental management – Life cycle assessment – Principles and framework* (ISO 14040:2006); German and English Version EN ISO 14040:2006, Beuth Verlag Berlin.

EN ISO 14044 (2006): *Umweltmanagement – Ökobilanz – Anforderungen und Anleitungen; Environmental management – Life cycle assessment – Requirements and guidelines* (ISO 14044:2006); German and English Version EN ISO 14044:2006, Beuth Verlag Berlin.

DIN-Fachbericht 107 (2000): *Umweltmanagement – Ökobilanz – Anwendungsbeispiele zu ISO 14041 zur Festlegung des Ziels und des Untersuchungsrahmens sowie zur Sachbilanz; Environmental management – Life cycle assessment* – Examples of application of ISO 14041 to goal and scope definition and inventory analysis, German and English Version ISO/TR 14049:2000. Beuth Verlag. Berlin.

DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (2005): *Dichtungssysteme an Deichen.* DWA Themen WW-7.3, Hennef.

Egloffstein, T. and Burkhardt, G. (1998). *„Vergleichende Öko-/ Energiebilanzen als Entscheidungshilfe für die Wahl des richtigen Oberflächenabdichtungssystems“*, Abfallwirtschaft in Forschung und Praxis, Band 109, Erich Schmidt Verlag, Berlin, 1998.

Egloffstein, T. and Burkhardt. G. (2005). *„Ökobilanzen für Oberflächenabdichtungssysteme – Ein Blickwinkel zur ganzheitlichen Betrachtung von Abdichtungen und Funktionsschichten“.* Abfallwirtschaft in Forschung und Praxis Bd. 135. Erich Schmidt Verlag. Berlin.

Egloffstein, T. (2009). *Ökologischer Vergleich zwischen Bauweisen mit mineralischen Baustoffen und Bindemitteln sowie Bauweisen mit Geokunststoffen*. Geotechnik 32 (2009) Nr. 3. VGE Verlag GmbH, Essen.

FFE Forschungsstelle für Energiewirtschaft der Gesellschaft für praktische Energiekunde e.V. (1999): *Ganzheitliche Bilanzierung von Grundstoffen und Halbzeugen. Teil I Allgemeiner Teil. Teil II Baustoffe*. Teil III Metalle. Teil IV Kunststoffe. München.

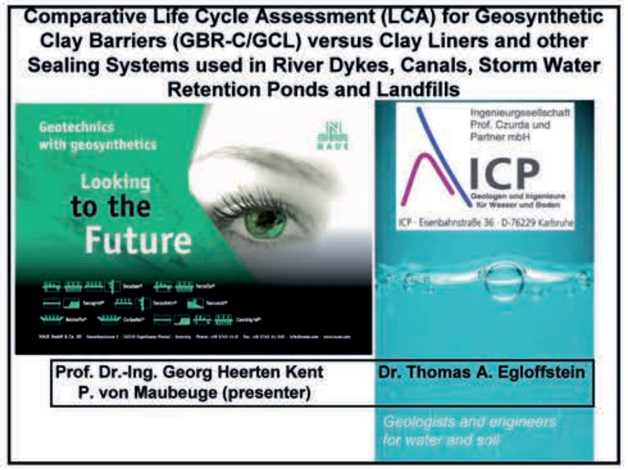
Grießhammer, R. (1996): *Entwicklungsziele für nachhaltige Produkte.* In: Eberle. U.. Grießhammer, R. (ed.) Ökobilanzen und Produktlinienanalysen. Ökoinstitut Verlag. Freiburg.

Klöpfer, W., Grahl, B. (2009): *Ökobilanzen (LCA): Ein Leitfaden für Ausbildung und Beruf.* WILEY-VHC Verlag, Weinheim.

SETAC Society for Environmental Toxicology and Chemistry (1993). *Guideline for Life Cycle Assessment – A „Code of Practice“*., SETAC Workshop held at Sesimbra, Portugal, 31 March – 3 April 1993, Edition 1, Brussels and Pensacola (Florida).

UBA Umweltbundesamt (1999): *KEA: Mehr als eine Zahl. Basisdaten und Methoden zum kumulierten Energieaufwand (KEA)*. Dessau.

Slides of the powerpoint presentation



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Prof. Dr.-Ing. Georg Heerten Kent
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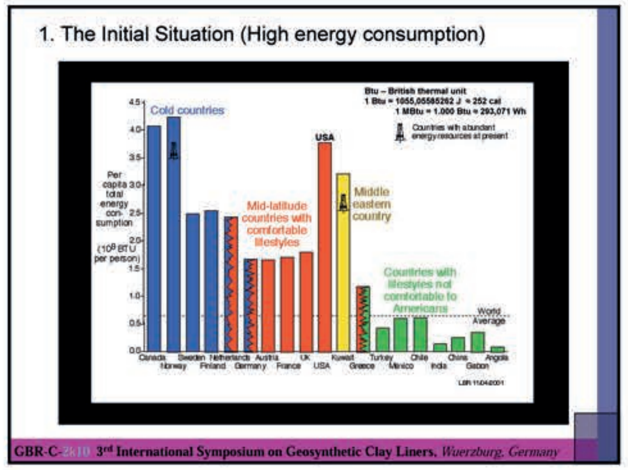
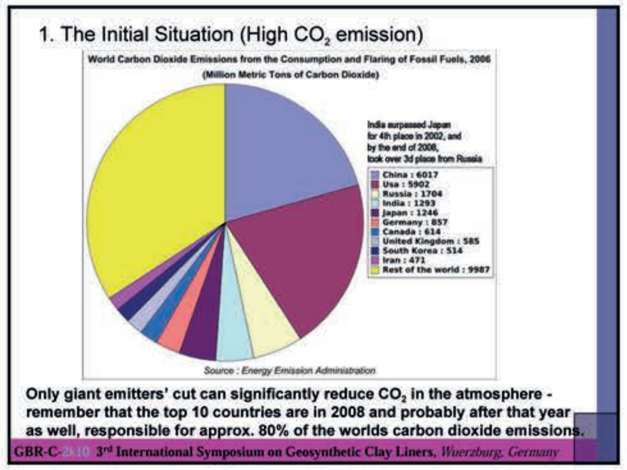
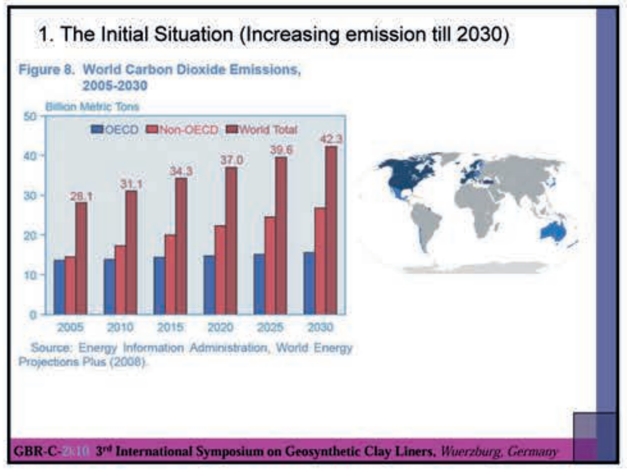


1. The Initial Situation (High energy consumption)

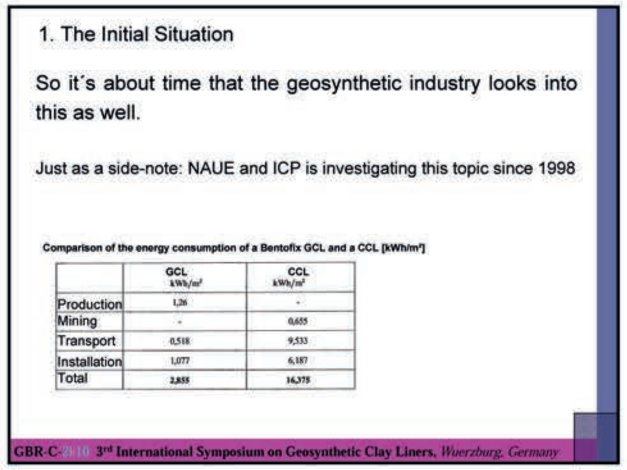


1. The Initial Situation (High CO_2 emission)

Only giant emitters' cut can significantly reduce CO_2 in the atmosphere - remember that the top 10 countries are in 2008 and probably after that year as well, responsible for approx. 80% of the worlds carbon dioxide emissions.



1. The Initial Situation (Increasing emission till 2030)



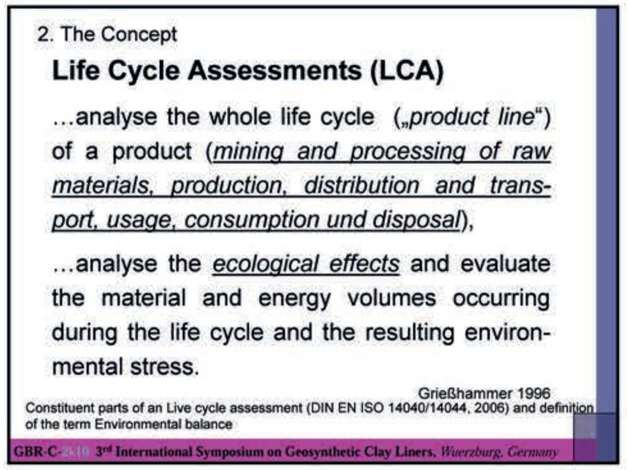
1. The Initial Situation

So it´s about time that the geosynthetic industry looks into this as well.

Just as a side-note: NAUE and ICP is investigating this topic since 1998

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

	GCL kWh/m²	CCL kWh/m²
Production	1,26	-
Mining	-	0,655
Transport	0,518	9,533
Installation	1,077	6,187
Total	**2,855**	**16,375**



2. The Concept

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.

Grießhammer 1996

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

2. The Concept

Cumulated energy demand (CED) in Life cycle assessments (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.

source UBA: http:*www.oeko.de/service/****kea****/dateien/****kea****-bau.pdf*

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2. The Concept

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

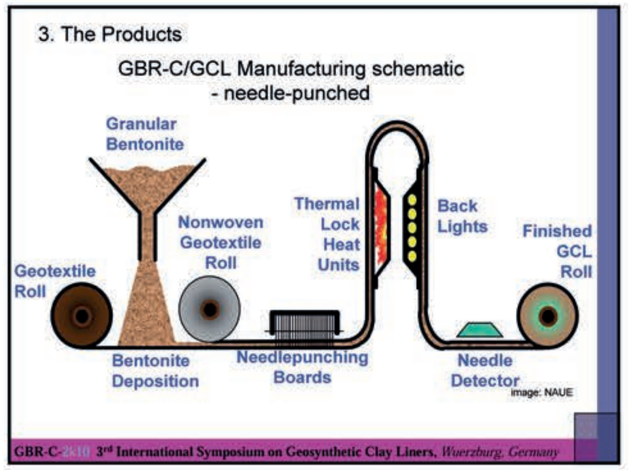
Representative for the environmental effects the CO_2-emission in kg per kg resp. m³ or in Mg resp. tons were selected with regard to the greenhouse potential.

3. The Products

GBR-C/GCL (needle-punched)

Bentonite Mining

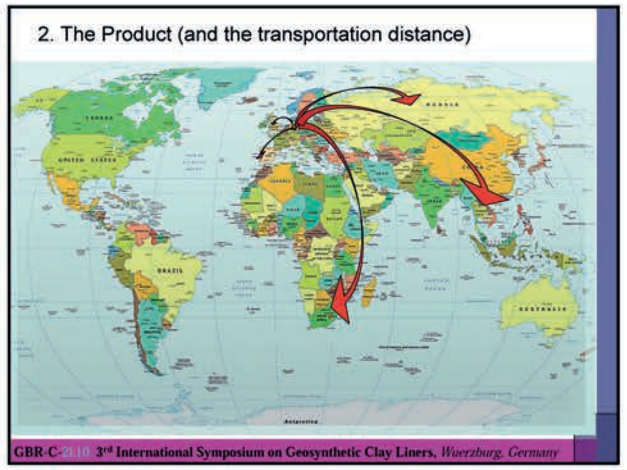
Foto: NAUE



3. The Products

GBR-C/GCL Manufacturing schematic
- needle-punched

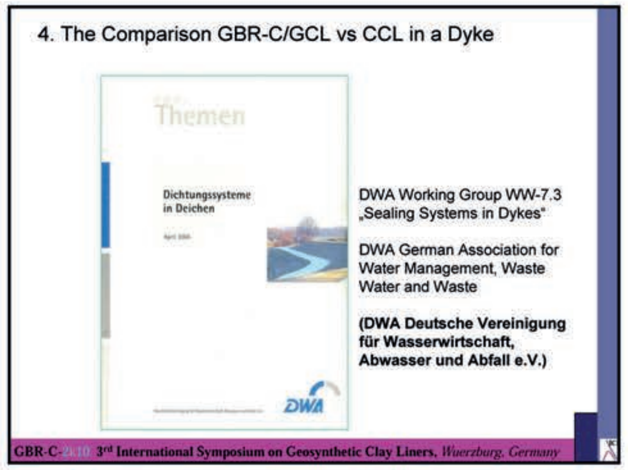
image: NAUE



2. The Product (and the transportation distance)

3. The Products

CCL Compacted Clay Liner

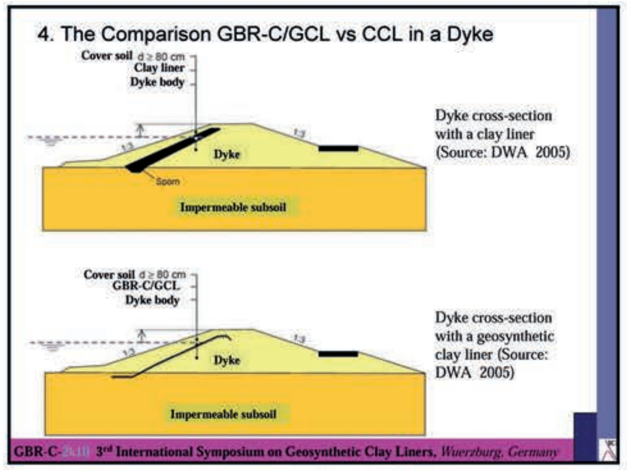


4. The Comparison GBR-C/GCL vs CCL in a Dyke

DWA Working Group WW-7.3 „Sealing Systems in Dykes"

DWA German Association for Water Management, Waste Water and Waste

(DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.)



4. The Comparison GBR-C/GCL vs CCL in a Dyke

Dyke cross-section with a clay liner (Source: DWA 2005)

Dyke cross-section with a geosynthetic clay liner (Source: DWA 2005)

4. The Comparison GBR-C/GCL vs CCL in a Dyke

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5. The Calculation

Cumulated energy demand (CED) – Emissions for PP resin and production

Product all values per kg	CED [MJ]	CO_2 [kg]	CO [g]	NO_X [g]	SO_2 [g]	CH_4 [g]	NMVOC 8,0[g]	N_2O [g]	dust [g]
Naphtha	47	0,365	0,6	2,2	1,0	4,3	8,0	0,0	0,2
Liquid gas	51,3	0,530	0,8	2,7	1,2	4,7	8,4	0,0	0,2
Gas oil	46,8	0,432	0,7	2,4	1,0	4,3	7,8	0,0	0,2
Ethane	52,2	0,495	0,8	2,7	1,2	4,8	8,6	0,0	0,2
Refinery gas by FCC	48,8	0,504	0,8	2,6	1,1	4,4	7,9	0,0	0,2
Propylene	56,1	0,962	0,8	2,8	1,3	5,2	8,8	0,0	0,2
for comparison: Propylene according to /Boust93b/		0,528	0,4	6,0	4,0	7,0		-	0,8

Cumulated energy demand (CED) and emissions for polypropylene granules production [MJ/Mg]

Product all values per kg	CED [MJ]	CO_2 [kg]	CO [g]	NO_X [g]	SO_2 [g]	CH_4 [g]	NMVOC 8,0[g]	N_2O [g]	dust [g]
Polypropylene resin	85,5	1,57	1,2	4,9	3,7	7,3	9,4	0,0	0,6
for comparison: Polypropylene acc. to /Boust93b/		1,10	0,7	10,0	11,0	13,0		-	2,0

Cumulated energy demand (CED) and emissions for polypropylene injection moulding parts production [MJ/Mg]

Product all values per kg	CED [MJ]	CO_2 [kg]	CO [g]	NO_X [g]	SO_2 [g]	CH_4 [g]	NMVOC [g]	N_2O [g]	dust [g]
Polypropylene injection moulding part	78,7	2,28	1,7	6,8	4,3	8,7	9,8	0,1	0,7

Integrated balance of basic materials and semi-finished products

http://www.ffe.de

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5. The Calculation

Table 1. Dyke sealing – Rehabilitation of the Kinzig dykes with compacted clay liners (CCL)

(Example: DWA Leaflet "Sealing systems in dykes")	Data / Units	Data / Units	Data / Units	**CED** [MJ]	CO_2 [kg]
Surface sealed:	36000 m^2				
Mineral sealing with a medium thickness of 62,5 cm	22500 m^3				
Soil extraction - covering with shovel excavator	22500 m^3		7.6 MJ/m^3	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 m^3		8.98 MJ/m^3	202050	16372
Compacting using a soil compactor in 2 - 3 layers of 0.5 - 0,33 m thicknes	22500 m^3		4.14 MJ/m^3	93150	7548
Total of cumulated energy demand (CED) [MJ] / Total CO2 [kg]				4403700	356832
CED [MJ/m^2] / CO2 [kg/m^2]				122.3	9.9

Table 2. Soil cover for sealing layers (CCL)

(Example: DWA Leaflet "Sealing systems in dykes")	Daten [Einh.]	Daten [Einh.]	Daten [Einh.]	**CED** [MJ]	CO_2 [kg]
Soil extraction - covering with shovel excavator	36000 m^3		7.6 MJ/m^3	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 m^3		8.98 MJ/m^3	258624	20956
Installation of top soil cover with the long-arm excavator d = 0.2 m	7200 m^3		1.97 MJ/m^3	14156	1147
Total of cumulated energy demand (CED) [MJ] / Total CO2 [kg]				3426380	277639
CED [MJ/m^2] / CO2 [kg/m^2]				95.2	7.7
CED [MJ/m^2] / CO2 [kg/m^2] for CCL and cover				**217.5**	**17.6**

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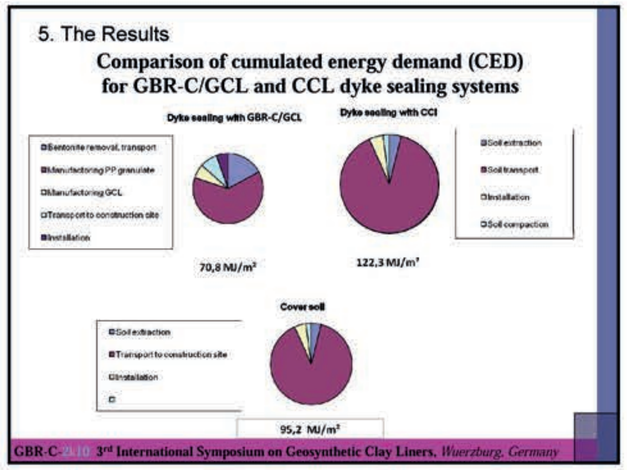
5. The Calculation

Table 1. Dyke sealing – Rehabilitation of the Kinzig dykes with GBR-C

(Example DWA Leaflet "Sealing Systems in Dykes")	Data / Units	Data / Units	Data / Units	CED [MJ]	CO_2 [kg]
Sealed surface (GCL measurements 45 x 4,8 m per roll)	36000 m^2				
GCL Bentofix B 4000 installed, surface weight 5.35 kg/m^2 incl. 6.2 %overlapping (30 cm with a 4,85 m mat width)	5.68 kg/m^2				
Bentonite, removal, transport to the manufacturer Naue Amount of bentonite per square meter 4,7 kg/m^2 incl. 6.2% overlapping (30 cm with 4.85 mat width)	4.99 kg/m^2	179666 kg	2.46 MJ/kg	441978	28747
Primary energy content (Feedstock):			47.50 MJ/kg		
Manufacture of polypropylene granulate:	0.69 kg/m^2	24840 kg	65.50 MJ/kg	1627020	56635
Manufacture of polypropylene geomembrane and material combination (suface weight 650 g/m^2 incl. overlapping)	0.69 kg/m^2		3.6 MJ/kg	89451	16623
Manufacture of GCL	5.68 kg/m^2		2.196 MJ/m^2	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 m^2		3.887 MJ/m^2	139932	11339
Total of cumulated energy demand (CED) [MJ] / Total CO2 [kg]				2585018	144855
CED [MJ/m^2] / CO2 [kg/m^2]				71.8	4.0

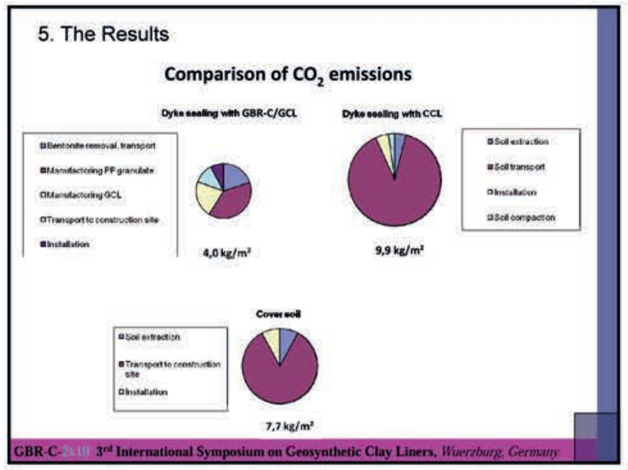
Table 2. Soil cover for sealing layers (GBR-C)

(Example: DWA Leaflet "Sealing systems in dykes")	Daten [Einh.]	Daten [Einh.]	Daten [Einh.]	**CED** [MJ]	CO_2 [kg]
Soil extraction - covering with shovel excavator	36000 m^3		7.6 MJ/m^3	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 m^3		8.98 MJ/m^3	258624	20956
Installation of top soil cover with the long-arm excavator d = 0.2 m	7200 m^3		1.97 MJ/m^3	14156	1147
Total of cumulated energy demand (CED) [MJ] / Total CO2 [kg]				3426380	277639
CED [MJ/m^2] / CO2 [kg/m^2]				95.2	7.7
CED [MJ/m^2] / CO2 [kg/m^2] for GCL sealing and cover				**167.0**	**11.7**



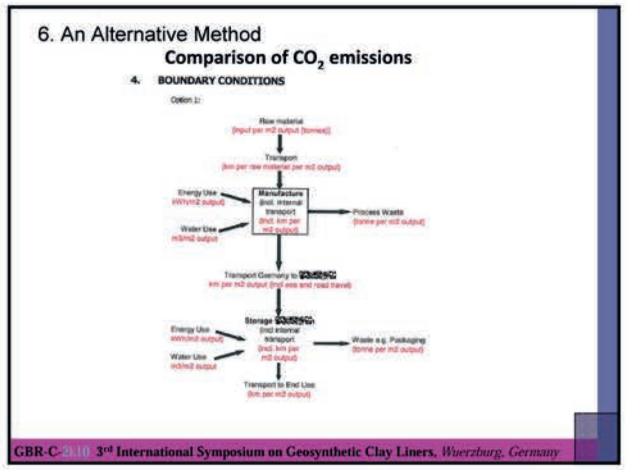
5. The Results

Comparison of cumulated energy demand (CED) for GBR-C/GCL and CCL dyke sealing systems



5. The Results

Comparison of CO_2 emissions

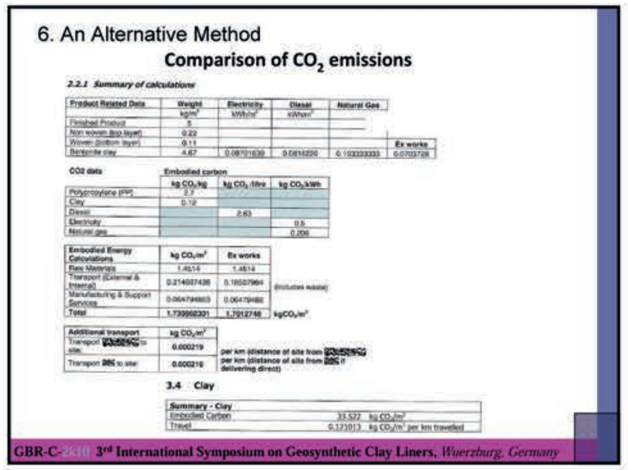


6. An Alternative Method

Comparison of CO_2 emissions

4. BOUNDARY CONDITIONS

Option 1:



6. An Alternative Method

Comparison of CO_2 emissions

2.2.1 Summary of calculations

Product Related Data	Weight kg/m²	Electricity kWh/m²	Diesel kWh/m²	Natural Gas	Ex works
Finished Product	5				
Non woven (top layer)	0.22				
Woven (bottom layer)	0.11				
Bentonite clay	4.67	0.08701639	0.0816220	0.103333333	0.0703728

CO2 data — Embodied carbon

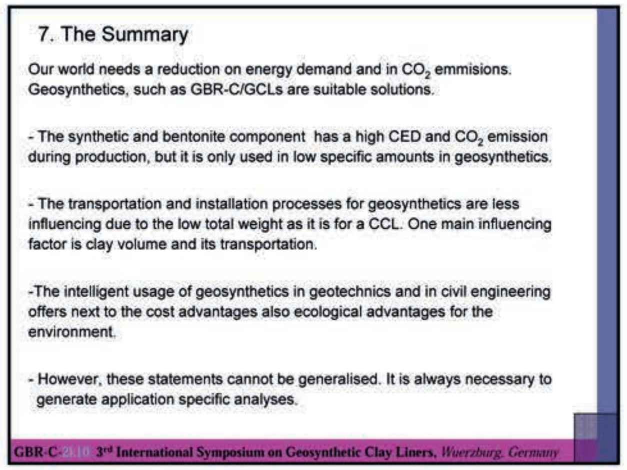
	kg CO_2/kg	kg CO_2 /litre	kg CO_2/kWh
Polypropylene (PP)	2.7		
Clay	0.12		
Diesel		2.63	
Electricity			0.5
Natural gas			0.206

Embodied Energy Calculations	kg CO_2/m²	Ex works	
Raw Materials	1.4514	1.4514	
Transport (External & Internal)	0.214007438	0.18507964	(includes waste)
Manufacturing & Support Services	0.064794803	0.06479486	
Total	1.730062301	1.7012748	kgCO_2/m²

Additional transport	kg CO_2/m²	
Transport [redacted] to site:	0.000219	per km (distance of site from [redacted])
Transport [redacted] to site:	0.000219	per km (distance of site from [redacted] if delivering direct)

3.4 Clay

Summary - Clay		
Embodied Carbon	33.522	kg CO_2/m²
Travel	0.171013	kg CO_2/m² per km travelled



7. The Summary

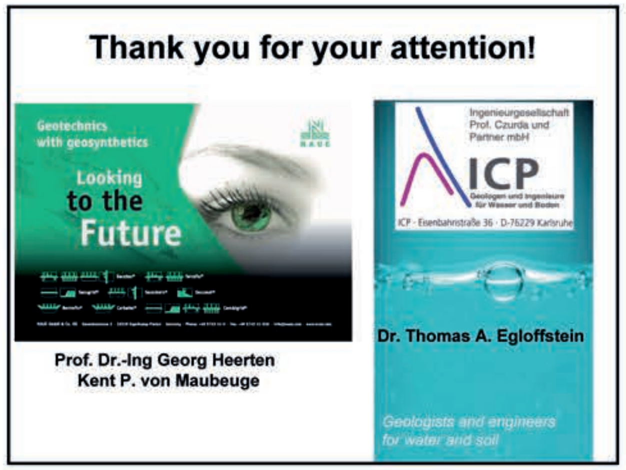
Our world needs a reduction on energy demand and in CO_2 emmisions. Geosynthetics, such as GBR-C/GCLs are suitable solutions.

- The synthetic and bentonite component has a high CED and CO_2 emission during production, but it is only used in low specific amounts in geosynthetics.

- The transportation and installation processes for geosynthetics are less influencing due to the low total weight as it is for a CCL. One main influencing factor is clay volume and its transportation.

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

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



Thank you for your attention!

Prof. Dr.-Ing Georg Heerten
Kent P. von Maubeuge

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