A Comparative LCA of Building Insulation Products

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Synbra has together with the Sustainable Development Group of AkzoNobel conducted an ex-ante Life Cycle Assessment (LCA) of BioFoam production from lactide produced from cane sugar in Thailand by Purac (Borén and Synbra 2010). An LCA allows holistic and quantitative environmental impact evaluations of economic systems, and facilitates relating environmental impacts to a functional unit.

With the goal to probe which of the materials BioFoam®, expanded polystyrene foam (EPS foam), polyurethane foam (PUR foam) and mineral wool (as produced today under average European conditions) that are most often used as thermal insulation products for buildings from an environmental point of view, a comparative life cycle assessment (LCA) of these materials has been performed by AkzoNobel. This model has been made to supply prospective customers a full LCA on their particular application and to compare it with insulants when used in insulation and with EPS cardboard when used as packaging. This is subject of another comparison.

BioFoam; is a polylactic acid based foam material that can be used as an alternative to traditional insulation materials. It has passed stringent stability tests on fire resistance moisture resistance, fungus resistance and attack by pests such as termites see cadre 2 and at use temperatures below 60°C does not degrade to any significant extend even after many years of exposure.

The functional unit of this LCA is the thermal resistance of 5 m²·K/W and the following environmental aspects are assessed: renewable and non-renewable energy use, abiotic resource depletion, global warming, acidification, photochemical oxidant formation, eutrophication and farm land use. The study focuses on the insulating and environmental properties of the insulation products per se, and the studied system includes the production, delivery and disposal (incineration with or without energy recovery, landfill with or without energy recovery, industrial composting or recycling) of the insulation products. The delivery and disposal is modelled for average European conditions. An external critical review has been carried out to validate that the methodology, data, interpretation and report of this LCA complies with the ISO 14040 standard series.

PUR foam and mineral wool as produced under average European conditions. It has been performed according to the ISO standards on LCA (ISO 14040 and 14044). The focus is on the production and disposal (recycling, incineration with or without energy recovery and composting) of the materials. Figure 1 presents a simplified flowchart of the studied system of this LCA. As the study focuses on the environmental properties of the insulation products per se, the application and use stages are excluded, and no regard is taken to situations which impose different demands concerning ancillary material and energy inputs in the application and future demolition and disassembly of insulated buildings, and it is noted that the conclusions may not be valid for such situations.

The system boundaries are defined by a system expansion approach as recommended by the ISO standards, meaning that only the activities affected by an additional demand of insulation product are included. This approach is best combined with marginal production data, however the difference between marginal and average production data for the activities in scope of this assessment is considered to be minor and therefore average production data has been applied for all activities for reasons of practicality. With regard to technical and temporal boundaries all industrial activities are modeled as if they would take place today within the current infrastructure. The application, use and final disposal of the insulation products is accounted for to take place in Europe. Where applicable average European LCA data has been applied for these activities.

The functional unit is defined in the ISO 14040 standard as 'the quantified performance of a product system for use as a reference unit in a life cycle assessment study'. The key performance aspect of thermal insulation products is that they are used for limiting the transfer, or conduction, of thermal energy, or heat. Thermal resistance, R, is the resistance of a material to the conduction of thermal energy, and is a measure of a material's insulating capacity. According to Schmidt et al. (2004) the thermal resistance measured in m²·K/W has been generally accepted as an adequate functional unit for LCAs of thermal insulation products. In this LCA the materials are compared on the basis of 1 m² of insulating material with an insulating capacity/thermal resistance of 5 m²·K/W.

The mass of an insulation product, m, required to achieve a certain thermal resistance can be defined according to:

$$m = R \cdot \lambda \cdot \rho \cdot A \quad (1)$$

Where R is the material's thermal resistance 5 m²·K/W; λ is the material's thermal conductivity (the property of a material that indicates its ability to conduct heat) measured as W/(m ·K); ρ is the material's density measured as kg/m³; A is the area in m², here 1 m²; K is degree Kelvin; W is Watt.

Based on this formula the mass of the studied materials that must be installed in order to achieve the functional unit, i.e. a thermal resistance of 5 m²·K/W, can be calculated (table 1). Knowing the mass and the area, the associated thickness, t, in cm, of the insulating product can also be calculated.

Table 1. Properties of the studied materials

Material	λ (mW/m·K)	ρ (kg/m³)	m (kg/F.U.)	t (cm)
BioFoam	36	20	3,6	18
EPS Foam	36	20	3,6	18
PUR Foam	26	40	5,2	13
Rock Wool	42	120	25,2	21

Table 2 and 3 presents the cradle-to-gate results for the production of the insulation products from 100% primary raw materials. Note that the CO_2 sequestration associated with the cultivation of sugar cane for PLA production is accounted for, see cadre1.

Table 2. Results for the production of 1 kg of the insulation products

	BioFoam	EPS Foam	PUR Foam	MWool
Non-Renewable Energy Use (gross calorific value) (MJ)	62	116	102	27
Renewable Energy Use (gross calorific value) (MJ)	56	1.0	1.5	2.7
Abiotic Resource Depletion (kg Crude Oil-Equiv.)	1.3	2.4	2.1	0.6
Global Warming Potential (GWP 100 yrs)(kg CO_2-Equiv.)	2.2	4.6	4.2	1.6
Acidification Potential (kg SO_2-Equiv.)	0.028	0.012	0.017	0.009
Photochem. Oxidant Formation (kg Ethene-Equiv.)	0.0028	0.011	0.0019	0.0008
Eutrophication Potential (kg Phosphate-Equiv.)	0.013	0.0013	0.0031	0.0011
Farm Land Use (m²/yr)	2.1	-	-	0.4

Table 3. Results for the production of the amounts of the insulation products needed to fulfil the functional unit (see table 1) Land use due to farm land resp. wood use in transport pallets

	BioFoam	EPS Foam	PUR Foam	MWool
Non-Renewable Energy Use (gross calorific value) (MJ)	222	418	529	687
Renewable Energy Use (gross calorific value) (MJ)	202	3	8	69
Abiotic Resource Depletion (kg Crude Oil-Equiv.)	4.6	8.7	10.6	13.9
Global Warming Potential (GWP 100 yrs)(kg CO_2-Equiv.)	8.1	16.6	21.8	41.3
Acidification Potential (kg SO_2-Equiv.)	0.10	0.04	0.09	0.22
Photochem. Oxidant Formation (kg Ethene-Equiv.)	0.010	0.039	0.010	0.020
Eutrophication Potential (kg Phosphate-Equiv.)	0.045	0.005	0.016	0.029
Farm Land Use (m²/yr)	7.6	0.013	-	9.8

With regard to recycling, the efficiency and use of take back schemes determines the recycling rate, and as of now there are apart for EPS no comprehensive take back schemes in place for most of the insulation products. From the results section it is evident that recycling should be pursued for environmental impact mitigation and that high recycling rates significantly reduce the environmental impact of BioFoam and EPS foam; a consequence of reduced demand for virgin lactide and expandable polystyrene. Whereas efficiency improvements of energy recovery from waste mainly achieves significant reductions for non-renewable energy use, abiotic resource depletion and global warming potential, improved recycling rates result in significant impact reductions in all impact categories.

The study demonstrates that an LCA provides an adequate analytical framework for the quantitative comparison of insulation products from an environmental impact perspective. The following aspects have been identified as key with regard to the environmental performance of insulation products:

- Insulating properties determining the material amounts required to achieve the insulating capacity
- The environmental impact associated with the production of the insulation products
- Post consumer treatment of the insulation products

It is clear that one insulation product cannot be unambiguously classified as the most environmentally benign alternative, as this depends on the relevance assigned to the different environmental impact categories.

However, considering only non-renewable energy use, abiotic resource depletion and global warming potential the insulation products can in general be ranked, starting with the most favourable alternatives, in the following order: BioFoam, EPS foam, PUR foam and mineral wool. It is evident that BioFoam can be recommended for insulation as an alternative to the other insulation products for reducing impact on climate change and dependence on fossil resources and for promoting the use of local and renewable resources.

Other key observations are:

- BioFoam has the highest eutrophication potential and renewable energy demand, the second highest acidification potential and requires use of farm land.
- BioFoam and PUR foam have the lowest photochemical oxidant formation potentials.
- EPS foam has the lowest contribution to acidification, however the highest contribution to photochemical oxidant formation.
- Mineral wool performs worst in 4 out of 8 impact categories, and not well in any impact category, due to that significantly more material is needed relative the other insulation products and has a significant land use related to mining.
- With regard to post consumer treatment BioFoam is the most flexible product, and is the only product which may be deliberately composted
- Recycling of EPS foam and BioFoam into new insulation products leads to significant environmental impact reduction and should in general be pursued to the extent possible. This is very difficult for PUR foam and Mineral wool which mostly are incinerated or end up in landfill respectively.

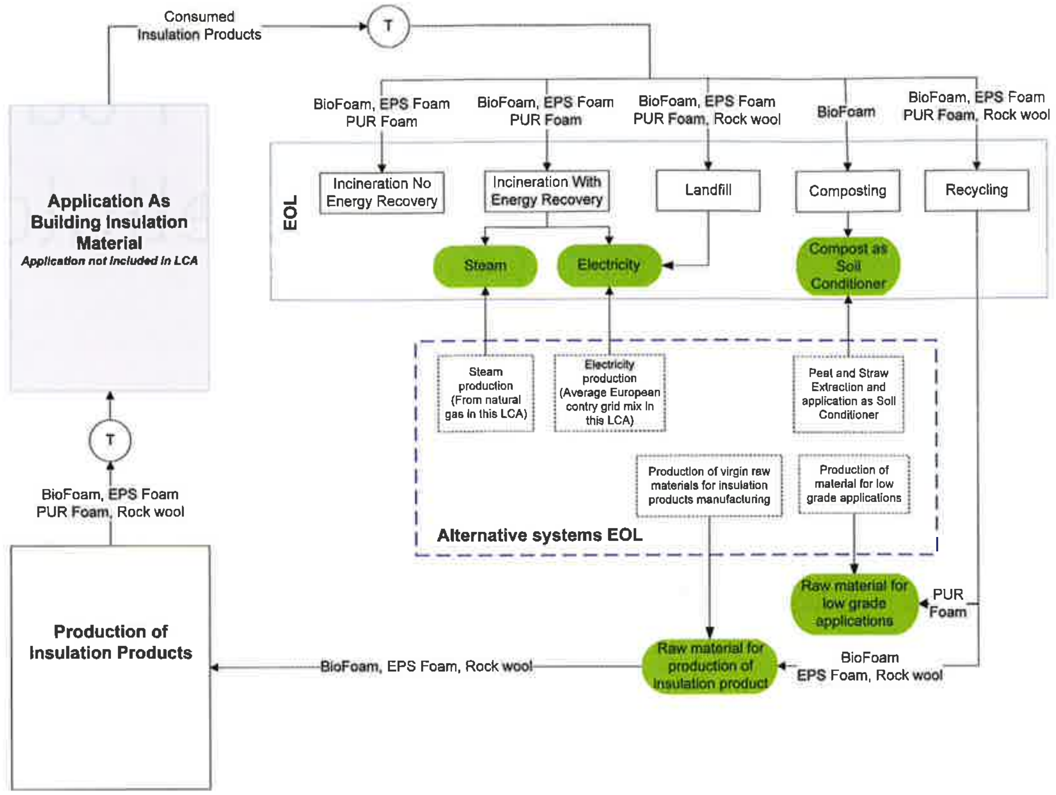
Cadre 1
LCA results Cradle-to-gate impacts of 1 kg lactide based PLA which is the amount of PLA needed to produce 1 kg of BioFoam using the Purac Sulzer polymerisation process.

Unit	Lactide based PLA needed for BioFoam
Non-Renewable Energy Use	38,642 MJ
Renewable Energy Use	55,763 MJ
Resources	0,79534 kg Crude Oil-Equiv.
Carbon Footprint incl CO_2 sequestering	0,9488 kg CO_2-Equiv.
Acidification	0,026551 kg SO_2-Equiv.
Photochemical Oxidant Formation	0,0025805 kg Ethene-Equiv.
Eutrophication	0,012426 kg Phosphate-Equiv.

Cadre 2
Critical test passed by BioFoam

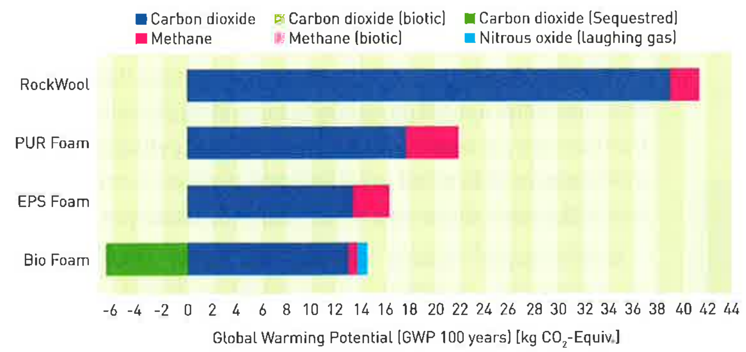
Flame retardant properties	EN 11925-2:2002	Meets Euroclass E for 30-40kg/m3 Test report R0529 Effectis (TNO) dd 22-4-2010
Flame retardant properties	DIN 4102-1	Meets all the requirement of class B2 No after burning observed.
Fire propagation properties	ECE R44/02	Tested in line with the automotive directive. TNO Effectis October 2009 Suitable for automotive usage
Termite and pest control	EN 117/118	High and Low density samples not attacked by termites, BioFoam is not a digestible feedstock Report TNO Delft 22-7-2010
Other properties	ISPM 15	No fungi, bacteria, splinters, rusty nails Hygienic, suitable for export without additional treatments
Mould formation	ISO 4833	Aerob mesofil colony forming units < 50 CFU after 3 weeks , better than EPS. Determined by Siliker Food safety and Quality solutions report 5-3-2010

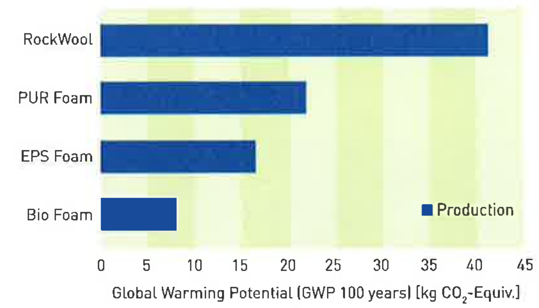
Figure 1. Flowchart of the studied system. EOL = End-of-life. T = Transport



Carbon Footprint, Global Warming Potential for a functional unit with R_c 5

	BioFoam	EPS Foam	PUR Foam	Mineral Wool
Global Warming Potential (GWP 100 years) incl. biotic CO_2 [kg CO_2-Equiv.]	8,1	17	22	41





Land Use for a functional unit of R_c 5

	BioFoam	EPS Foam	Mineral Wool
Land use (Farming & Forestry) [m²yr]	7,56	0,013	9,8