FINAL REPORT

QUALITY CONTROL SUMMARIZING REPORT

LIFE12 ENV/FI/000592 UPACMIC

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Project name	**UPACMIC**
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CONTENT

ANNEX

GLOSSARY OF TERMS

By-product — Secondary product which is produced as side stream from primary production.

Life cycle — Successive or interactive stages of the product system from the extraction or production of raw materials from natural resources to final disposal [1].

Life cycle assessment (LCA) — Compiling and evaluating product system life cycle inputs and outputs and potential environmental impacts [1].

Life cycle cost (LCC) — Is defined as the cost of an asset or its parts throughout its life cycle while the performance requirements [3].

Life cycle impact assessment (LCIA) — Life cycle assessment phase to understand and evaluate the extent and significance of the potential environmental impacts of a product system throughout the product life cycle [1].

Product — Any good or service [1].

Product system — Series of unit processes with elementary streams and product flows that perform one or more specified functions and describe the product life cycle [1].

1. INTRODUCTION

UPACMIC project has been funded by the EU Life12 program (LIFE12 ENV/FI/000592). Project targets were to demonstrate technically and environmentally feasible alternative for remediating mine sites. UPACMIC project is supposed to promote utilization of industrial by-products in mine remediation structures, reduce needs for virgin materials and save nature values. Extensive mine areas offer a great potential for reclaimed material usage and thus enable positive environmental impacts of using them. Technology is already used in other infrastructure projects and now in the mining environment. Low carbon footprint, application potential and feasible technical is supporting the usage of them.

Pyhäsalmi mine is located in Pyhäjärvi, Finland. The mine produces copper, zinc and pyrite. It was opened in 1962 and activities are still going on, but the mine is gradually closing its operations. Tailing sands in Pyhäsalmi have sulphate concentration and it is an acid draining waste. Pilot structures were constructed in 5/2016 and removed in 11/2019. Tailings' acidification and seeping water properties were monitored to research cover structures affect to those. Pilot structures monitoring results are presented in report *"B1 final technical report on piloting"* This report presents the results of long-term monitoring.

Hitura Mine is located in Northern Ostrobothnia in Nivala, Finland. Hitura mine has started to operate in 1970 and mining operations has ended in 2013. The amount of quarried ore is 17,2 Mt and ore of the mine consist nickel approximately 0,5% and copper 0,1%. The most significant owner of the mine was Belvedere Mining company. Mining was first performed opencast mining and continued to underground mining. There are total 15 Mt of tailing sand and 7 Mt of mining waste rock deposited to Sulphur containing serpentine rock pile and sulphide mineral content mica gneiss pile. The quarried rock was also utilized in rockfill. Hitura mine is no longer in operation but the tailing sand areas needed to be closed in order to block seeping of rainwater through tailing sand. Closing of the mine is on the responsibility of the state because the mine owner company Belvedere Mining went bankrupt in 2015. Closing was carried in two stage – first stage in the years 2017-2018 and second stage during the years 2019-2020. UPACMIC pilots were at the first closing phase fiber clay sealing layer and at the second closing phase there were constructed landscaping structure using only surplus materials and reactive water treatment structures.

Quality control and assurance were continuously done during actions A3 (material testing) and A4 (applications). In A4 action created quality control plans is concretized in action B1 (piloting) where the quality control is essential part of pilot constructions, so quality control which is done in those actions is not focused on this report. Results of previously mentioned actions are reported in *A3 Final technical report, A4 Final report on applications* and *B1 final technical report on piloting*. In this report is focused pilots follow-up and has compared different quality control methods by using SWOT charts.

2. LONG TERM FOLLOW-UP RESULTS OF PILOTS IN PYHÄSALMI MINE

2.1 Lysimeter test setup

Different cover layer structures were tested in Pyhäsalmi Mine. In the field tests, 5 different cover layer structures were tested for both coarse and fine tailing sands. Lysimeters were implemented in 2016 as 10 m^3 lysimeter structures. Total number of lysimeters was 10. Tested materials were earlier tested in the laboratory and the objective of the field tests was to study materials in real circumstances. Focus in the lysimeter tests were to complement laboratory studies (water permeability and leaching characteristics) with the seeping water results. When the lysimeters were built, notes were taken especially on the material handling, mixing and compacting. The materials chosen for the lysimeters were the most interesting and potential ones which could be used larger scale pilot cover structures later. The material layers in the structure and thickness in each lysimeter are presented Figure 1. The construction of the lysimeters are described in the report *"B1 Final technical report of piloting"*.

The bottom wells and lysimeter wells were emptied 2-5 times in month and the seepage water amount was measured. The quality of the seepage water was monitored after 42, 134, 165, 233, 345, 375, 453/459 days. The samples were collected during one-week period from the lysimeter well between emptying. The seepage water amounts varied during the test due to weather conditions. The sampling was carried out by the personnel of Pyhäsalmi Mine. Results from this follow-up are presented in the report *"B1 Final technical report of piloting"*. In this report is focused only on the last water samples that were taken just before the structures were disassembled.

Lysimeter water samples were analyzed for Al, As, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, V, Zn, Ca, K, Mg, Na and S (µg/l) and also for sulfate, fluoride, chloride and DOC (mg/l). The focus in this study was the leachability of the main components in the tailing sand Cu, Fe, Zn, S, Ca and sulfate. In addition, pH and conductivity were measured weekly, on average, at the same time when the lysimeter wells were emptied. Samples were analyzed in Ahma Ympäristö Oy (present Eurofins Ahma Oy) laboratories in Rovaniemi.

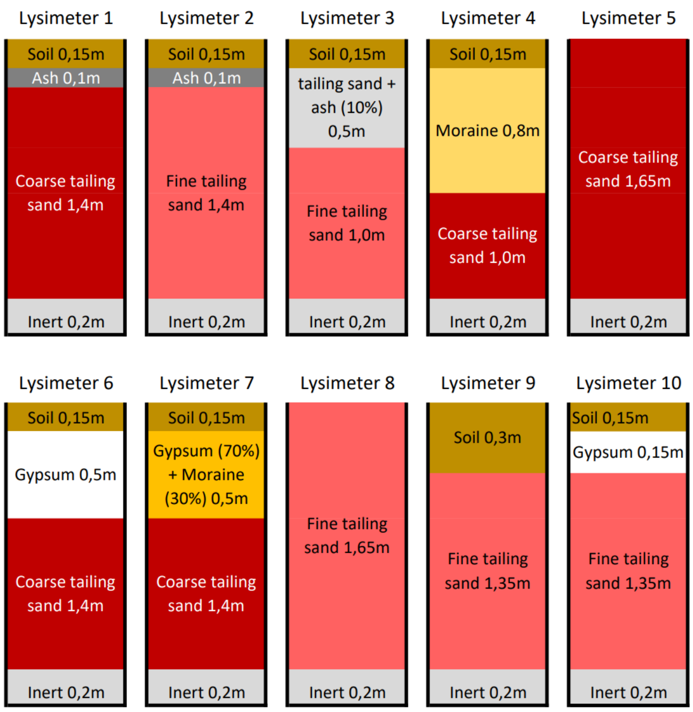


Figure 1. The layer structure of the tested lysimeters in Pyhäsalmi Mine.

2.2 Material analysis results before test

Metal total concentrations and leachability were tested from materials which are used in lysimeters. The total concentrations are shown in table 1 and leachabilities determined with 2-stage batch leaching test are shown in table 2. Based on the results Pyhäsalmi's tailing sands includes high concentrate of sulphate (S) and iron (Fe), and also aluminum (Al). High concentrations in same harmful metals are also in ash.

Table 1. Total concentrations and material properties of the used construction materials.

Material	Al (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Ca (mg/kg)	S (mg/kg)	pH	ρ_d (kg/m^3)
Tailing sand (fine)	7180	680	297000	590	1680	25400	294000	7,0	1870
Tailing sand (coarse)	6910	720	315000	430	2180	20700	310000	6,7	2380
Ash	52400	120	142000	2430	240	72100	12800	9,5	830
Gypsum	340	13	400	21	20	277000	215000	2,8	1290
Moraine	12800	55	17500	240	63	5040	350	4,8	2300
Inert material	11000	20	20800	190	33	6570	210	7,5	-

Table 2. Material solubilities (2-stage batch leaching test).

Material	DOC	Sulfate	Chloride	Fluoride	Al	As	Ba	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	V	Zn	Ca
											Leachability L/S = 10 (mg/kg)										
Moraine	<50	280	<50	<5	0,94	<0,15	0,43	<0,015	<0,1	0,2	0,68	<0,005	5,8	<0,05	0,12	<0,15	<0,01	<0,02	<0,05	2,1	49
Gypsum	<50	17500	<50	2190	4,1	1,5	0,06	0,049	<0,1	4,3	35,3	<0,005	17	<0,05	0,47	<0,15	<0,01	0,031	0,11	20,9	6620
Fly ash	<50	16600	924	<5	110	<0,15	1,00	<0,015	0,5	<0,1	<0,15	<0,005	<0,1	3	<0,1	<0,15	<0,01	0,067	0,1	<0,1	6100
Coarse tailing sand	<50	17300	<50	6	<0,3	<0,15	0,21	0,11	<0,1	<0,1	<0,15	<0,005	54	<0,05	0,42	<0,15	<0,01	0,023	<0,05	21	6410
Fine tailing sand	<50	18100	<50	6,1	<0,3	<0,15	0,19	0,054	<0,1	<0,1	<0,15	<0,005	38	<0,05	0,21	<0,15	<0,01	0,02	<0,05	11	6390
Inert material	<50	<50	<50	<5	0,63	<0,15	0,093	<0,015	<0,1	<0,1	0,56	<0,005	0,063	<0,05	<0,1	<0,15	<0,01	<0,02	<0,05	<0,1	15

2.3 Long term follow-up results

Long term follow-up of lysimeters included analysis of seepage 5.11.2019. Detailed follow-up (metal and anion analyses) was carried out around one year In addition, the pH, EC and redox were measured.

2.3.1 Seepage water surveillance

Seeping water has been monitored actively during 2016-2017. After that sampling interval is extended first to over 5 months and then 1,5 years. The last water samples are taken just before tearing down the lysimeters. Seeping water monitoring is reviewed precisely in report *B1 Final technical report of piloting*, so in this report is focused to just the last water samples (long-term follow-up).

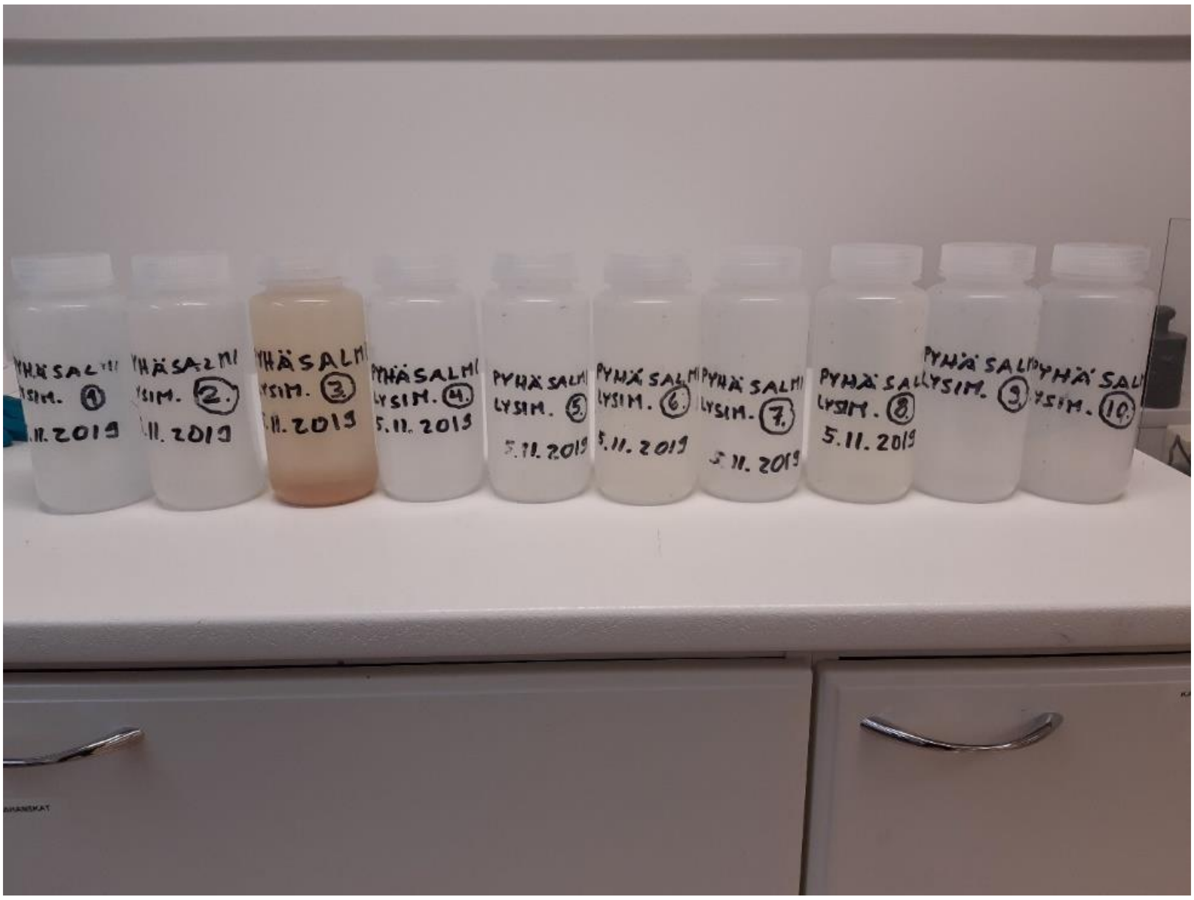


Figure 2. Water samples which were taken just before disassembling of the pilot structure.

Table 3. Measured values from samples which were taken on 5.11.2019 (sulphate g/L).

	PH	REDOX	EC	DOC	fluoride	cloride	Suphate	Ca	K	Mg	Na	S
			[mS/cm]	mg/L	mg/L	mg/L	g/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lysimeter 1	7,5	183	6,6	1,86	0,26	8,98	4,67	268	119	903	40,8	1570
Lysimeter 2	8,1	165	13,08	6,40	1,03	12,50	12	285	84,6	2390	34,5	3740
Lysimeter 3	6,6	22	16,16	11,60	<1,00	7,48	15,9	300	227	2980	71,6	4940
Lysimeter 4	8,0	131	4,78	2,16	<0,200	2,18	2,44	210	15,6	460	14,7	803
Lysimeter 5	6,5	220	9,74	4,37	<0,400	4,19	9,12	320	100	1440	33,8	2620
Lysimeter 6	8,1	166	20,2	7,79	1,19	4,54	21,5	285	74,9	4090	19	6440
Lysimeter 7	8,2	172	6,6	2,81	0,26	1,13	3,34	192	36	623	78,7	981
Lysimeter 8	7,7	184	21,5	10,10	4,67	4,41	20,5	238	115	3990	18,4	6350
Lysimeter 9	7,8	185	3,1	2,42	<0,200	15,20	1,46	298	34,7	141	33,8	484
Lysimeter 10	5,4	260	3,97	1,55	<0,200	5,90	1,17	183	43	119	198	370

	Zn	Ni	Cu	Fe	Al	Ba	Mn	V	Cd
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Lysimeter 1	1720	40,70	2,80	<4,0	<4,00	18,40	9290	0,28	5,48
Lysimeter 2	116	<2,00	6,90	<10,0	<10,0	26,40	5180	1,98	0,25
Lysimeter 3	2050	42,20	<5,0	11600	<10,0	23,20	17200	<0,250	0,69
Lysimeter 4	64,40	<2,00	1,90	2,10	<2,00	8,80	6,48	0,96	<0,020
Lysimeter 5	5520	152	2,30	5,90	10,60	23,50	39300	<0,100	2,64
Lysimeter 6	442	4,88	<10,0	24,00	<20,0	31,10	20600	4,63	<0,200
Lysimeter 7	123	<2,00	2,20	<2,0	<2,00	15,20	170	0,69	0,04
Lysimeter 8	555	6,69	<10,0	<20,0	<20,0	22,20	12600	1,46	0,65
Lysimeter 9	120	3,18	1,50	<2,0	<2,00	17,70	783	0,21	0,19
Lysimeter 10	225	33,90	6,10	13,00	570	13,10	1160,00	0,10	1,05

As you can see from tables 3 results of uncovered lysimeters 5 and 8 are noticeable worse than covering method. Figure's 2 sample 3 color can be explained with high iron content in sample. Its iron content is 11,6 mg/l which is several hundred time higher than in other samples. It is not sure which material (ash or tailing sand) the iron is coming from, but it is sure that oxidation is substantially occurred. Both materials contain iron but before construction made 2-stage batch leaching tests not much iron was leached from those.

It seems that traditional cover layers (4=moraine & 9=only thin growth layer) works fine. Layers which contain gypsum (lysimeters 7 & 10) seems work quite well. The 6^{th} lysimeter where gypsum layer is thicker than others perform worse than previously mentioned gypsum variants. Lysimeter 10 low pH compared to other is most likely result from much lower amount of seeping water than in others (water can't pass the well compressed thin gypsum layer) and due to that the sand may stay dry. That leads oxygen contact between sand and air which causes sands oxidation and acid formation.

Lysimeters that contains ash (1,2 and 3) perform poorly compared to traditional covering options. Mixing ash with tailing sand (lysimeter 3) seems resulting worser (higher Zn, Ni, S and Fe concentration & lower pH) conditions than no cover at all (compared to lysimeter 8).

The results of comparison of seeping water concentration differences of covered structures to uncovered ones as percentage are showed on table 4. In the table lysimeters are arranged as the coarse and fine tailing sands are compared separately.

Table 4. Percentage difference of structures.

difference %	Ph	REDOX	EC	DOC	Fluoride	Cloride	Suphate	Ca	K	Mg	Na	S
			[mS/cm]	mg/L	mg/L	mg/L	g/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lysimeter 8	0	0	0	0	0	0	0	0	0	0	0	0
Lysimeter 2	5,194805	-10,3261	-39,1628	-36,6337	-77,9443	183,4467	-41,4634	19,7479	-26,4348	-40,1003	87,5	-41,1024
Lysimeter 3	-14,2857	-88,0435	-24,8372	14,85149	-78,5867	69,61451	-22,439	26,05042	97,3913	-25,3133	289,1304	-22,2047
Lysimeter 9	1,298701	0,543478	-85,5814	-76,0396	-95,7173	244,6712	-92,878	25,21008	-69,8261	-96,4662	83,69565	-92,378
Lysimeter 10	-29,8701	41,30435	-81,5349	-84,6535	-95,7173	33,78685	-94,2927	-23,1092	-62,6087	-97,0175	976,087	-94,1732
	Ph	REDOX	EC	DOC	Fluoride	Cloride	Suphate	Ca	K	Mg	Na	S
			[mS/cm]	mg/L	mg/L	mg/L	g/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lysimeter 5	0	0	0	0	0	0	0	0	0	0	0	0
Lysimeter 1	15,38462	-16,8182	-32,2382	-57,4371	-34,25	114,3198	-48,7939	-16,25	19	-37,2917	20,71006	-40,0763
Lysimeter 4	23,07692	-40,4545	-50,924	-50,5721	-50	-47,9714	-73,2456	-34,375	-84,4	-68,0556	-56,5089	-69,3511
Lysimeter 6	24,61538	-24,5455	107,3922	78,26087	197,5	8,353222	135,7456	-10,9375	-25,1	184,0278	-43,787	145,8015
Lysimeter 7	26,15385	-21,8182	-32,2382	-35,6979	-35,5	-73,031	-63,3772	-40	-64	-56,7361	132,8402	-62,5573
	Zn	Ni	Cu	Fe	Al	Ba	Mn	V	Cd			
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L			
Lysimeter 8	0	0	0	0	0	0	0	0	0			
Lysimeter 2	-79,0991	-70,1046	-31	-50	-50	18,91892	-58,8889	35,61644	-62,1329			
Lysimeter 3	269,3694	530,7922	-50	57900	-50	4,504505	36,50794	-82,8767	6,491499			
Lysimeter 9	-78,3784	-52,4664	-85	-90	-90	-20,2703	-93,7857	-85,7534	-70,9428			
Lysimeter 10	-59,4595	406,7265	-39	-35	2750	-40,991	-90,7937	-93,0822	62,28748			
	Zn	Ni	Cu	Fe	Al	Ba	Mn	V	Cd			
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L			
Lysimeter 5	0	0	0	0	0	0	0	0	0			
Lysimeter 1	-68,8406	-73,2237	21,73913	-32,2034	-62,2642	-21,7021	-76,3613	178	107,5758			
Lysimeter 4	-98,8333	-98,6842	-17,3913	-64,4068	-81,1321	-62,5532	-99,9835	858	-99,2424			
Lysimeter 6	-91,9928	-96,7895	334,7826	306,7797	88,67925	32,34043	-47,5827	4530	-92,4242			
Lysimeter 7	-97,7717	-98,6842	-4,34783	-66,1017	-81,1321	-35,3191	-99,5674	593	-98,4091			

When comparing percentage differences of results, lysimeters 4,7,9 and 10 seems perform well against uncovered structure. Lysimeter 1 cover structure seems work decently, but concentration difference is not as high as lysimeters 4 and 7.

2.4 Lysimeter layers comparison

In addition, the material samples were taken from each lysimeter layers during the deconstruction in 11/2019. The samples were analyzed for pH, redox and metal total concentrations. Test results are shown in table 5.

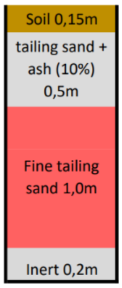
Table 5. Material analysis results from lysimeter layers.

Structure samples 5.-6.11.2019			mg/kg dw.					
Sample	**pH**	**REDOX**	**Cu**	**Fe**	**Ni**	**Zn**	**Ca**	**S**
1 / ASH 0,05m	7,1	290	178	135000	56,2	1040	62700	26800
1 / TS 0,1m	3,0	413	898	283000	7,3	2310	19200	261000
1 / TS 0,3m	5,7	120	891	285000	9,4	3670	20400	269000
1 / TS 0,5m	7,2	146	884	313000	8,3	2320	17600	336000
1 / TS 0,7m	7,3	159	899	291000	8,5	2460	21400	319000
1 / TS 0,9m	7,4	156	806	272000	8,9	2380	19500	253000
1 / TS 1,1m	7,2	119	835	275000	9,0	2600	19800	259000
1 / BOTTOM	6,5	15	752	270000	10,1	2160	19400	252000
2 / ASH 0,05m	7,2	222	143	144000	64,3	599	57700	7180
2 / TS 0,1m	2,6	451	654	298000	5,0	826	14800	262000
2 / TS 0,3m	4,4	247	1020	272000	8,4	3650	21600	255000
2 / TS 0,5m	6,7	191	1030	279000	8,8	2700	22400	262000
2 / TS 0,7m	7,1	182	862	282000	8,8	1680	21400	268000
2 / TS 0,9m	7,1	167	843	274000	8,0	2360	20000	266000
2 / TS 1,1m	7,2	145	749	299000	7,5	1800	19200	312000
2 / TS 1,3m	7,4	152	660	283000	8,4	1480	20000	267000
3 / TS+ASH 0,1m	2,5	459	574	208000	7,1	213	31500	205000
3 / TS+ASH 0,2m	3,2	354	1080	285000	14,0	1440	27400	256000
3 / TS+ASH 0,3m	4,2	237	797	264000	17,2	2700	26000	241000
3 / TS 0,1m	5,8	70	797	263000	13,9	2640	25500	241000
3 / TS 0,3m	5,9	69	658	273000	6,5	1420	21000	258000
3 / TS 0,5m	7,5	120	670	287000	9,5	1490	22100	271000
3 / TS 0,7m	6,2	26	627	294000	8,5	1280	20300	345000
3 / TS 0,9m	6,5	45	663	288000	8,3	1430	20800	320000
4 / MR	NOT ANALYZED							
4 / TS 0,1m	7,4	151	917	279000	11,2	2660	22300	263000
4 / TS 0,35m	7,4	142	785	285000	7,4	2420	17800	264000
4 / TS 0,6m	7,3	112	750	316000	9,2	2250	14400	352000
5 / TS 0,1m	2,8	431	664	287000	5,4	662	18100	288000
5 / TS 0,3m	2,9	358	1030	299000	9,5	2120	15900	273000
5 / TS 0,5m	4,6	172	774	296000	11,5	4260	15400	327000
5 / TS 0,7m	5,3	94	786	319000	9,4	3790	16200	334000
5 / TS 0,9m	6,7	147	748	310000	8,0	2700	16400	352000
5 / TS 1,1m	5,6	59	787	300000	7,2	2300	17000	318000
5 / TS 1,3m	6,8	66	764	309000	9,2	2320	17000	326000
5 / TS 1,6m	7,3	115	726	330000	11,4	2220	15500	372000

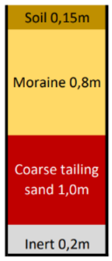
Lysimeter 1

Lysimeter 2

Lysimeter 3

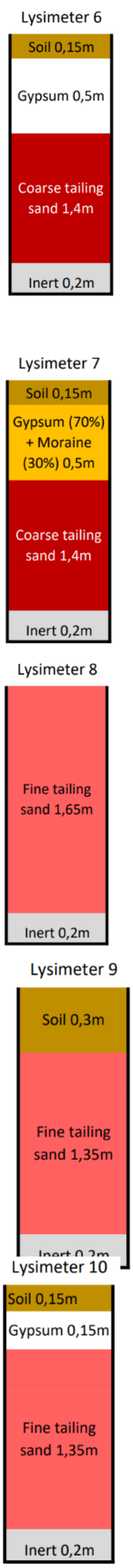


Lysimeter 4



Lysimeter 5

Sample	pH	REDOX	Cu	Fe	Ni	Zn	Ca	S
6 / GY	NOT ANALYZED							
6 / TS 0,1m	4,9	196	871	280000	11,2	2220	19100	262000
6 / TS 0,3m	6,9	120	726	284000	7,1	2250	16900	302000
6 / TS 0,5m	5,2	105	803	307000	12,2	4150	19600	295000
6 / TS 0,7m	5,4	30	879	329000	11,1	3850	19200	338000
6 / TS 0,9m	5,7	96	751	318000	9,5	3510	19200	330000
7 / MR+GY	NOT ANALYZED							
7 / TS 0,1m	7,1	141	749	374000	10,2	2320	21300	366000
7 / TS 0,3m	7,2	129	830	314000	9,6	2420	17800	330000
7 / TS 0,5m	7,2	140	687	292000	7,0	2150	17100	316000
7 / TS 0,7m	7,3	99	887	323000	9,4	2130	17900	319000
7 / TS 0,9m	7,2	118	736	310000	9,0	2230	17700	334000
8 / TS 0,1m	2,4	466	616	281000	<5,0	142	21100	285000
8 / TS 0,3m	2,8	406	649	304000	6,2	1300	19500	270000
8/ TS 0,5m	5,0	153	1130	307000	11,9	3710	17800	320000
8 / TS 0,7m	5,7	82	714	334000	12	2620	17400	355000
8 / TS 0,9m	6,8	90	1080	295000	10,1	3540	22500	300000
8 / TS 1,1m	7,0	78	801	311000	9,3	2330	18400	326000
8 / TS 1,3m	6,9	84	701	326000	6,3	2100	16600	342000
8 / TS 1,55m	7,6	85	799	322000	11,2	2050	16800	348000
9 / TS 0,1m	8,8	21	759	315000	13,2	2660	19400	335000
9 / TS 0,3m	8,6	62	700	336000	11,6	2220	16200	358000
9 / TS 0,5m	8,4	52	1000	322000	12,1	2680	21800	346000
9 / TS 0,7m	8,5	58	716	313000	10,5	2130	17600	352000
9 / TS 0,9m	8,5	17	751	318000	9,8	2500	20800	339000
9 / TS 1,1m	8,4	58	699	311000	9,4	2020	15800	335000
9 / TS 1,3m	7,8	89	674	321000	10,2	2120	13800	346000
10 / GY	NOT ANALYZED							
10 / TS 0,1m	8,0	113	590	298000	8,9	1300	20100	319000
10 / TS 0,3m	8,4	84	619	278000	8,7	1280	17600	263000
10 / TS 0,5m	8,1	76	864	319000	8,4	2260	18800	333000
10 / TS 0,7m	7,7	95	769	274000	8,4	1360	23200	259000
10 / TS 0,9m	7,9	48	555	239000	5,9	889	19800	243000
10 / TS 1,1m	8,9	55	567	308000	7,3	1400	17800	323000
10 / TS 1,3m	8,1	93	652	248000	7,6	1150	17700	280000



* two measurements

ASH = Ash	TS = Tailing sand

GY = Gypsum	MR = moraine

Compared results from samples that are taken layer by layer are shown in table 5. Total amount of elements, pH, redox are analyzed from samples.

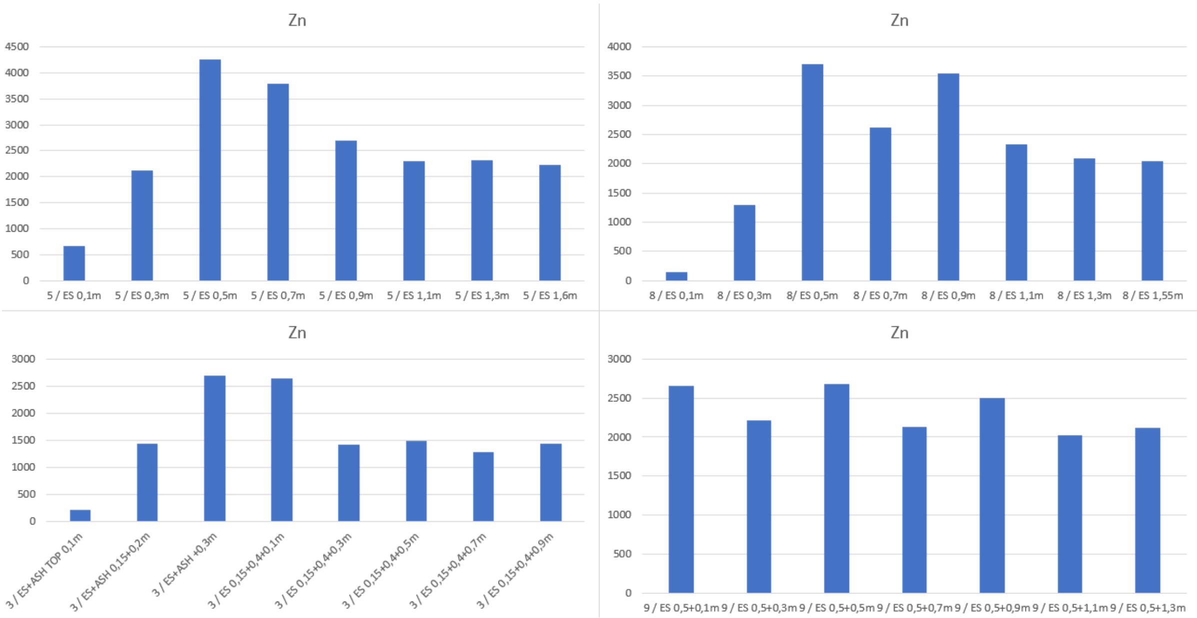


Figure 3. Zinc content in different layer of lysimeters. Top left and right are uncovered lysimeters 5 and 8. Bottom left and right are fly ash mixture covered lysimeter 3 and thin soil covered lysimeter 9.

In the figure 3 the layers are taken deaper fhen mowing left to right on the figure's columns. As can see from figures 3 comparison of layers, zinc has dissolved almost completely from top layer of uncovered lysimeters. Thin soil layer seems prevent zinc dissolving. Ash mixing with tailing sand does not give same level leaching protection. Leaching is most likely results from tailing sands oxidation. The sand reacts with air's oxygen and that produces acids which decreases seeping waters pH value. Layers pH values are compared in figure 4.

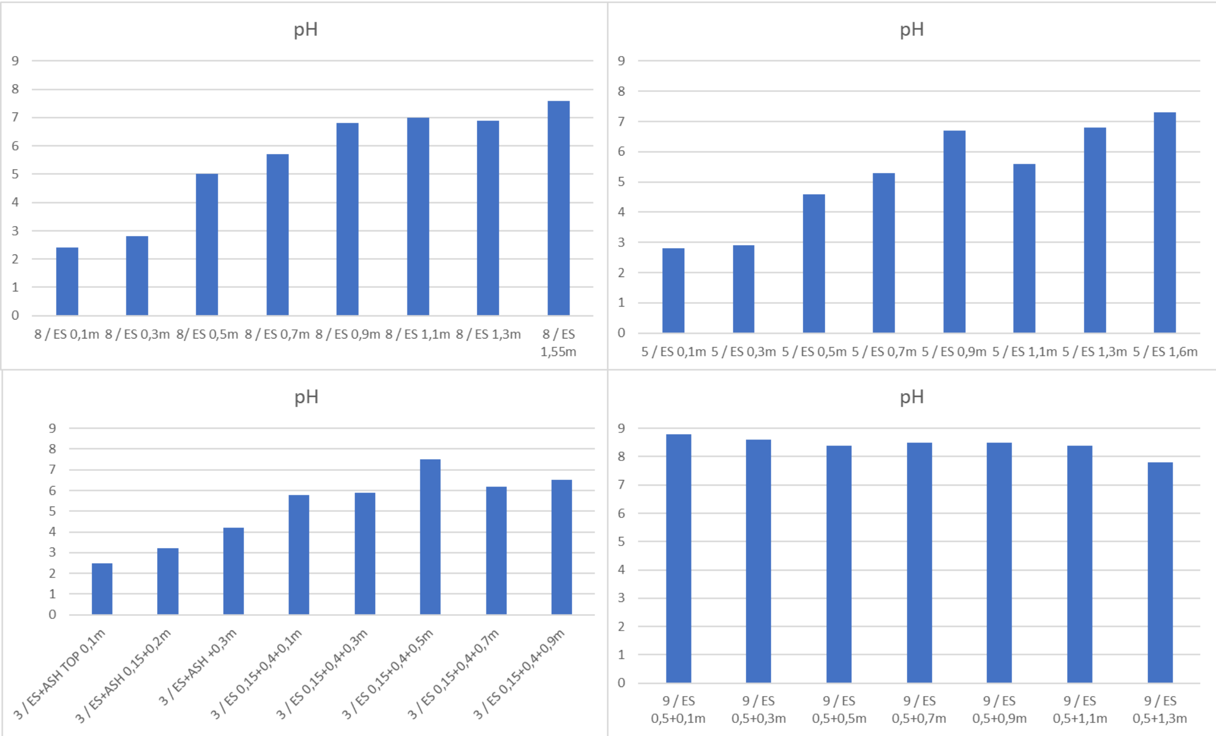


Figure 4. Lysimeter 3,5,8 and 9 pH values in different layers.

As can see from figure 4, top layers pH values are much lower than deeper layers at uncovered lysimeters. That is result from sands contact with air. In lysimeter 9 300 mm soil layer seems to prevent air contact and pH stays at good level through lysimeter' layers.

In lysimeters 1 and 2 the ash layer' pH seems to be good (>7) but after that the pH drops to 3,0 and 2,6 in next layers after the ash layers.

Gypsum is naturally acidic and its pH normally rises near neutral level over a time. However, in this lysimeter cover structure testing gypsum composing lysimeters behave oddly. Lysimeter 6 which contain 500 mm gypsum layer is at pH value 5-6 through tailing sand layers in lysimeter but pH in other two lysimeter which contain gypsum (7 & 10) seems to be at good level (>7 and 7,7- 8,9). Reason for lysimeter 6 low pH value is not clear and its tailing sand is coarse type which is considered less reactive and hazardous. Lysimeter 7 is also coarse, and its pH is at neutral level. Lysimeter 10 is constructed using fine tailing sand which is considered more reactive and hazardous which should decrease pH due to acid formation, but pH stays at good level. One reason for this kind of behavior may occurred when fine tailing sand stay wet due to capillarity. Capillarity may not occur with coarse sand, and it may dry between rains. Wet sand doesn't get so much contact with air and pH stays at good level.

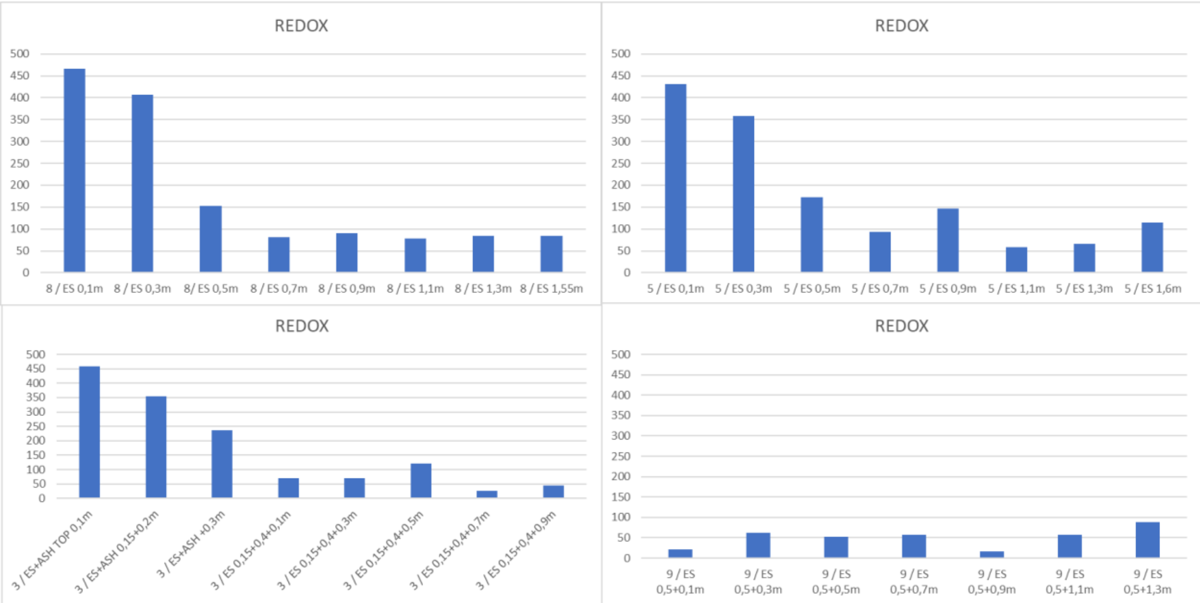


Figure 5. Lysimeters 3 5 8 and 9 redox potentials as mV.

When comparing redox potentials in different structures(figure 5), redox-potential results support previous assumed events. Top layers of lysimeters 8 and 5 tailing sands have high redox potential which indicate that oxidation was occurred and when moving deeper in structure the redox potential decreases to neutral level (0-100 mV). Redox potentials are low which means that tailing sand inside the lysimeter 9 is in stationary state.

2.5 Conclusion

In long-term testing the moraine, growth soil and mixture of gypsum & moraine seems perform the best. This kind of fly ash in this extent seems not suit for covering layer as reactive layer or mixed with tailing sand. As can see from figure's 2 lysimeter 3 cover where ash mixing with tailing sand may even worsen leaching of metals. However, results of structures which composes gypsum were mixed. Gypsum needs more long-term testing and observation to get certain results. Tested fly ash seems not suit for cover structures if just wanted improve cover layer's performance. Fly ash may help reduce amount of needed virgin constructing materials which need to take in consideration. It also must notice that every fly ash is unique and fly ash from some other source may perform better than tested one.

With side stream materials the production rate may be the handicapping factor when considered larger scale application. Example tailing sand basins sealing structures needs a lot of materials which create great demand. To fulfil these demands one structure type is not enough but maybe multiple different combination of multiple different materials will be solution. Tailing sands are also different so one cover solution may not work in other location. When considered structure with multiple combination the quality control is in big role to maintain good quality level throughout the structure.

3. LONG TERM QUALITY CONTROL OF FIBER CLAY SEALING LAYER PILOT IN HITURA MINE

Sealing layer is made of fiber clay that is approved for the intended use on the basis of pretests (leached tests and test compactions). The demands for the covering structure in Hitura when fiber clay is used in sealing layer were:

- The water permeability k ≤ 1,0 x 10^{-8} m/s.
- The area where fiber clay is used must be bearing and dry.
- Layer thickness ≥ 250 mm (+50/-0 mm).
- The levelness/evenness of the sealing layer is constantly visually estimated.
- The requirement ±50 mm and no depression for collecting water.
- The compaction requirement (dry density requirement) is determined according to the preliminary tests and field test results.
- The sealing layer is compacted with the suitable equipment. Surface of the layer is levelled even.
- On top of the finished layer/coating must not be driven with machines that can cause deformations or loosing material from the coating.

3.1 Lysimeter test setup

In Hitura site has been build 5 identical lysimeter side by side. Lysimeters dimensions are width 1000 mm and height 300 mm. Lysimeter was filled with tailing sand and amount of it inside lysimeter is about 235 l. On top of those are same material layers as in sealing layer pilot structure in Hitura's mine second tailing sand basin and reference lysimeter 5 have only tailing sand without cover layer. Layers tightness are same as in pilot structures. First three are constructed by using fiber clay from Mänttä, Oulu and Äänekoski. Each fiber clay layer tightness is 250 mm and on top of it is 200 mm moraine layer and 100 mm growing layer (which is also moraine suitable for growing). Fourth is constructed as traditional alternative solution with 250 mm compressed moraine layer and 200 mm moraine layer and 100 mm growth layer (moraine about 550 mm). Last lysimeter is leaved uncovered as reference to simulate situation where tailing sand wasn't covered at all. Lysimeters cross-section cut is in figure 6. Fiber clay sealing layer structures plans and test structures were approved by the Centre for Economic Development, Transport and the Environment.

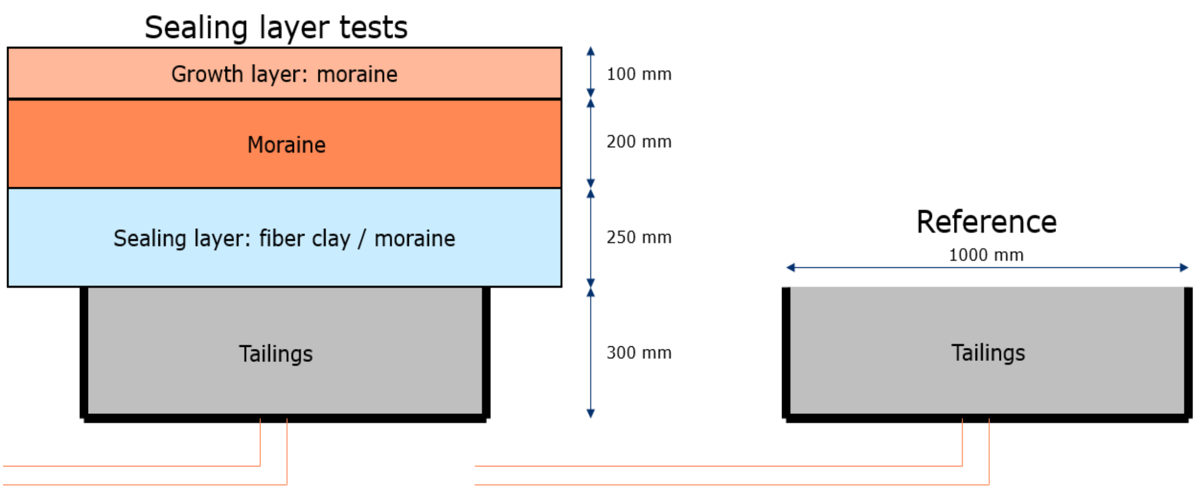


Figure 6 Lysimeter test setup cross-section cut.

Monitoring is started autumn 2020 and it will continue at least end of year 2022. During the monitoring the seeping water quality and quantity were analyzed. At this report are compared the results from first 16 months. Quality is monitored with sampling and quantity with tipping bucket flow meter. From quality samples were analyzed for Al, Ca, Co, Cu, K, mg, Mn, Na, Ni, Si and Zn (mg/l) and, also for pH, electrical conductivity and sulfate were analyzed.

Assumption is that tailing sand's amount and composition is equal in each lysimeter and moraine & growth layers are identical so only chancing variable is sealing layer.

3.2 Test results

Table 6 is listed cumulative amount of water which is gone through each lysimeter.

Table 6. Seeping water monitoring results and L/S ration on end of monitoring period.

	Fiber clay Oulu	**Fiber clay Äänekoski**	**Fiber clay Mänttä**	**Moraine**	**No cover**
10.8.2020	5,7	1,2	14	2	1,3
8.9.2020	5,7	1,2	14,1	2	1,3
22.10.2020	10,4	1,2	14,1	49,3	1,8
19.11.2020	58,3	29,3	30,8	135,3	15,4
10.12.2020	87,6	47,1	42,4	177,5	26,4
19.1.2021	88,1	47,2	42,4	177,5	26,5
18.2.2021	88,1	47,2	42,4	177,5	26,5
29.3.2021	88,1	47,3	42,4	177,6	26,5
21.4.2021	90,7	47,3	42,4	180	31,9
1.5.2021	91,2	47,3	44	180	32,1
31.5.2021	101	58,2	51,5	191,9	37,4
14.7.2021	101	58,3	51,8	191,9	39,1
8.9.2021	101,2	58,3	51,8	191,9	45,2
3.11.2021	134,1	74,4	81,6	205,3	57,3
9.12.2021	136,9	83,3	83,6	207,8	57,9
L/S ratio	0,33	0,20	0,20	0,51	0,14

In table 7 is listed environmental qualifications follow-up results. There is different amount of sampling points due to ether water doesn't flow through structure or collecting bucket is drowned in results of spring flood at the area. At least from two time point is got sample for metal analysis so some estimation can be done.

Table 7. Samples for environmental friendliness follow-up.

Sealing layer	Sample date	pH	EC [mS/cm]	SO_4^{2-} [mg/l]	Cu [mg/l]	Fe [mg/l]	Mn [mg/l]	Ni [mg/l]	Zn [mg/l]
Oulu	22.10.2020	8	14,76	15888	0,031	< 0,05	24	2,2	0,22
	19.11.2020	7,61	27,3	15828	0,037	< 0,05	19	1,6	0,08
	18.2.2021	7,67	12,53	12529	0,011	0,04	4,7	0,34	0,049
	3.11.2021	7,9	15	18000	0,076	< 0,025	5,5	0,63	0,42
Äänekoski	19.11.2020	7,76	26,1	15715	0,037	< 0,05	25	4	0,14
	18.2.2021	7,73	15,68	34142	0,035	< 0,01	18	2,4	0,065
	3.11.2021	7,9	17	24000	0,064	< 0,025	9	1,5	0,62
Mänttä	10.8.2020	7,43	29,1	15900	0,021	0,012	43	9	0,12
	3.11.2021	7,8	15	23000	0,025	< 0,025	11	1,5	0,23
Moraine	22.10.2020	7,8	8,61	15833	0,025	< 0,05	18	2,7	0,056
	18.2.2021	7,58	2,75	1608	0,005	< 0,015	1,5	0,22	0,029
	3.11.2021	7,7	7,6	7600	0,051	< 0,025	0,019	0,25	1,1
No cover	22.10.2020	7,5	11,95	15820	0,025	< 0,05	39	6,3	0,1
	18.2.2021	7,41	5,44	5416	0,0051	< 0,01	5,7	0,9	0,019
	14.7.2021	6,5	3,84	3695	0,14	0,037	3,5	0,83	0,26
	8.9.2021	7	5,81	6571	0,02	0,038	0,42	1	0,19
	3.11.2021	7,5	6	5800	0,017	< 0,025	0,12	0,8	0,086

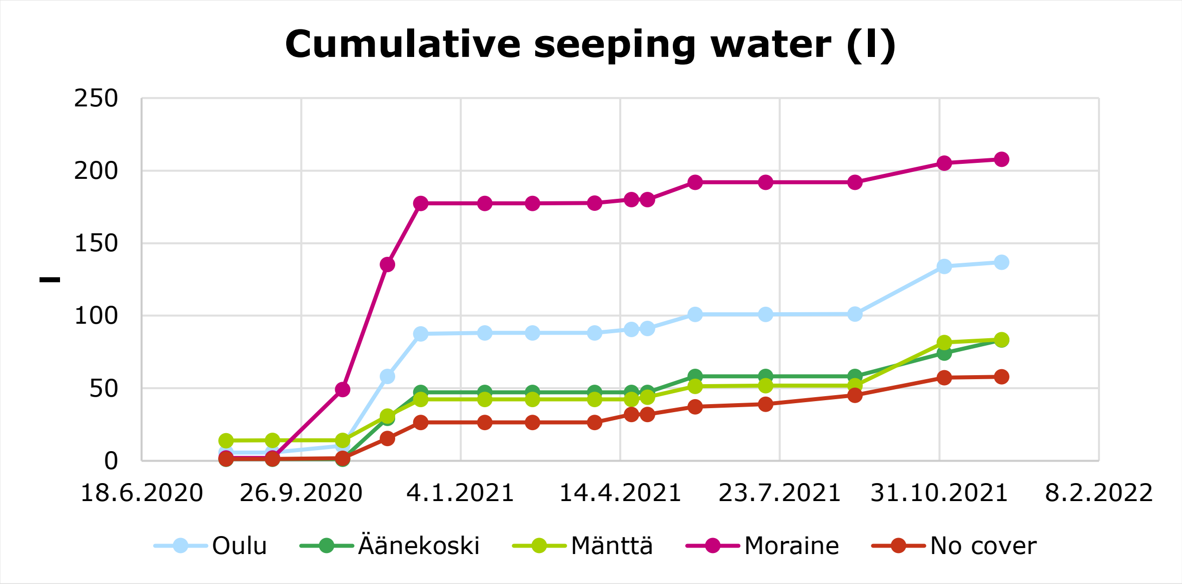


Figure 7. Seeping waters cumulative amount in each topping.

As can see from figure 7 the moraine lets most water through. Next is Oulu's fiber clay, which let water through about half as much as moraine. Mänttä's and Äänekoski's fiber clays seems behave equally in terms of water permeability and let through half as much water as Oulu's fiber clay. No cover option behaves oddly and let through least amount of water. That may indicate that growing layer act as a sponge and reduce runoff water. Tailing sand may not be at same water permeable level as growth layer is and rainwater just runoff from the surface of tailing sand in lysimeter 5. Amount of water which seeped through the structure also affect the cumulative results of dissolved pollutants total amounts.

Cumulative results are calculated by multiplying the integrated concentration of pollutants with amount of seeping water between measuring points, the most significant results are presented in figures 8-10.

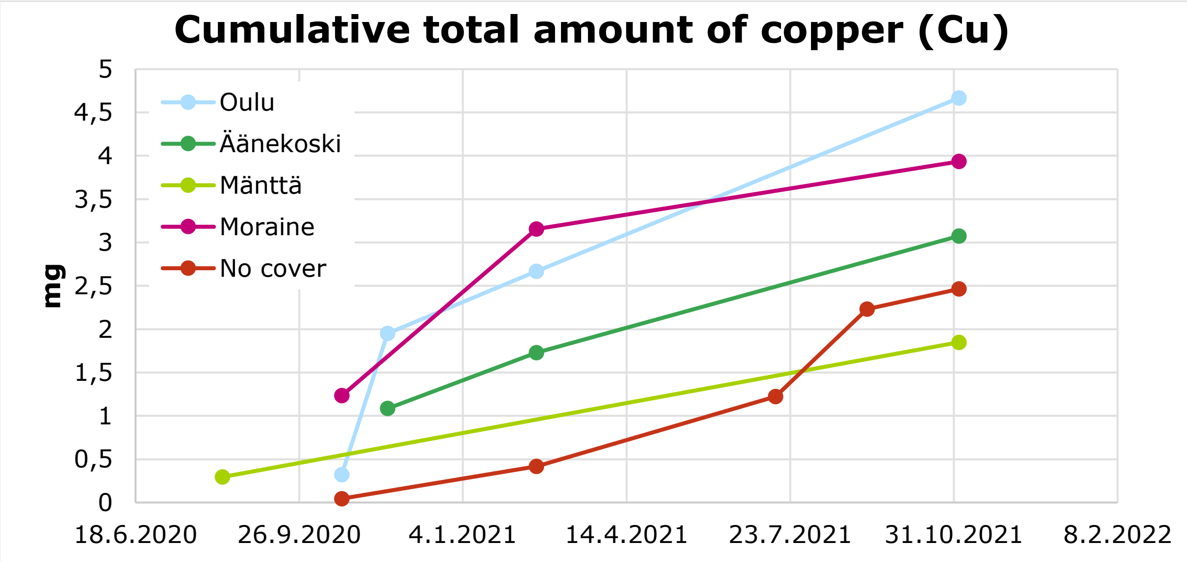


Figure 8. Estimated copper amount which is leached from tailing sand.

Figure 8 is compared total amount of leached copper. The moraine and Oulu's fiber clay structures has the most copper leaching. Fiber clay from Mänttä seems work best and Äänekoski's little bit worse. No cover option seems to be worst when remembered that it lets least water through during the monitoring period. The quantity must be notice as the under 5 mg leaching during over a year monitoring period is not much compared to the amount of tailing sand (235 l). That is about 407,4 kg sand per lysimeter when tailing sand's density is 1734 kg/m^3.

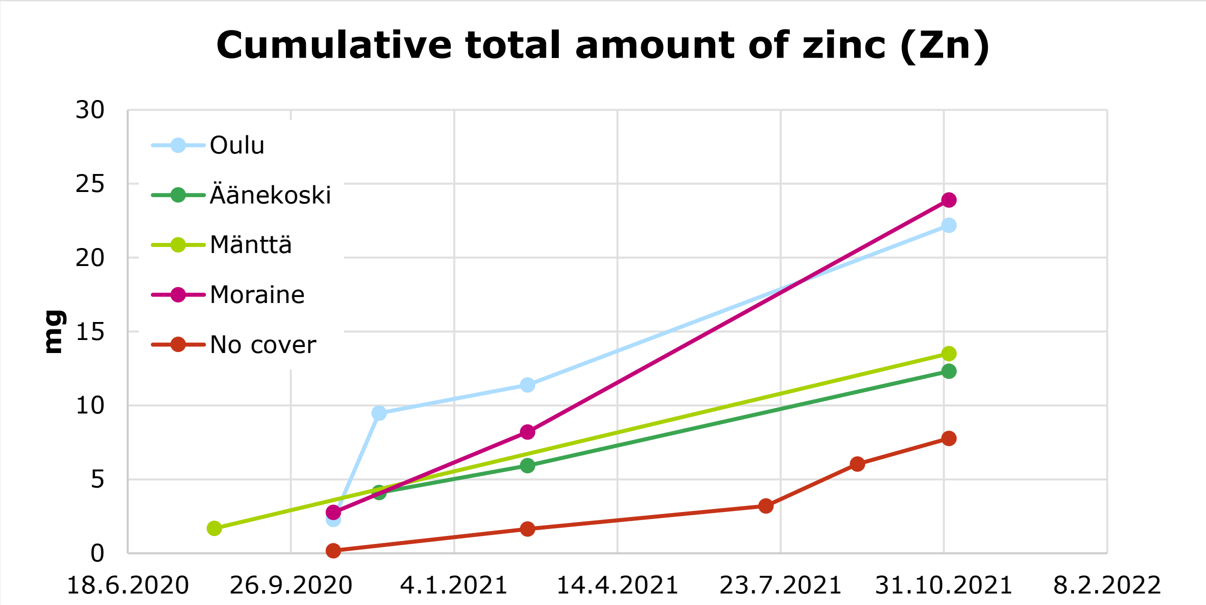


Figure 9. Estimated zinc amount which is leached from tailing sand.

In figure 9 is compared cumulative leached amount of zinc. Based on the figure 9 no cover -option seems to be the best. Fiber clay from Oulu and moraine are worsts, Äänekoski and Mänttä seems act identically. The magnitude of zinc leaching is not remarcable compared to nickel which is shown in following figure 10. Leached amount of nickel was the smallest in no covered option. Moraine and fiber clay from Mänttä seems to be worsts sealing material, since cumulative amount of nickel in Mänttä was almost 500 mg, which was about 200 mg more than in moraine option.

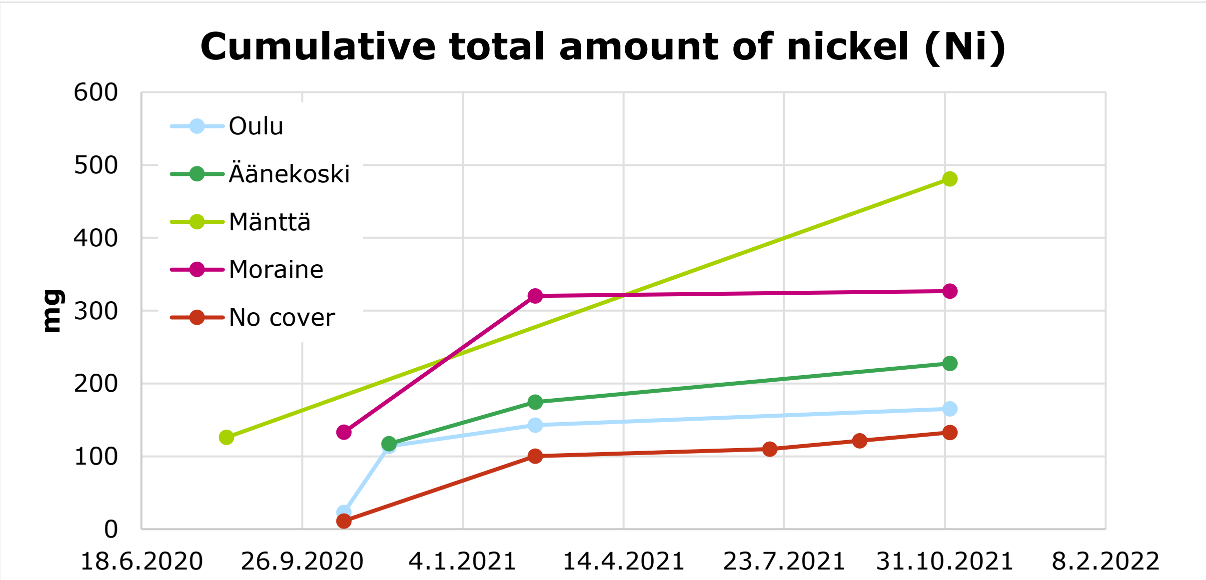


Figure 10. Estimated nickel amount which is leached from tailing sand.

3.3 Critical evaluation

When comparing leached nickel amount Mänttä's fiber clay performing the worst next is moraine. Oulu's and Äänekoski's fiber clays act almost the same. Uncovered structure seems to be the best option, but the amount of seeping water was lower, when the concentration is higher. The reason behind uncovered lysimeters illogical result can be seen from figure 11. Rainwater doesn't have time to infiltrate to the tailing sand and it just runoff from lysimeter. Runoff water has made grooves on the ground. In other structures water infiltrate in moraine topping and have time to seep through cover layers. Result won't give real indication of seepage water, because in real world rainwater would stay in swallows and slowly infiltrate through tailings.

Figure 11. Uncovered lysimeter.

When comparing sealing materials from every aspect, Oulu's fiber clay performed the best when comparing leached metals amounts. When comparing only seeping water amounts, the Äänekoski's fiber clay is the tightest material. Äänekoski's fiber clay let low amount seeping water through, and total amounts of leached metals are low. Moraine is the worst cover option of these because it let through most water and amount of leached metals are also high. All the results verifies that sealing layer constructed by recovered materials, have better quality than cover layer by traditional materials.

4. REACTIVE STRUCTURE PILOTING IN HITURA MINE

4.1 Reactive barrier test setup

Reactive structures construction and monitoring results are presented in piloting report *"B1 Final technical report on piloting"*. In this report is focused to renewal of mats in reactive structure. After renewal the mats are followed, and the results are compared to previous test results.

Used mats environmental qualification is tested by batch leaching test and these results are compared to waste classification threshold values in Finland. The waste classes are inert, ordinary and hazardous waste. If the mats are classified as ordinary or common waste those would be easy to dispose to ordinary landfill.

4.2 Mats renewal

Mats renewal is done by using contractor and excavator. Before renewal the water flow is stopped by adjusting valves. First step of renewal is removing gravel layer from on top of the mats. Second step is mats lifting out from pond using excavator which is performed in figure 12.
Third step is relevelling of lower gravel layer which were deformed due to ground frost during winter. Forth step is new mats installation by rolling them over the lower gravel layer. Fifth step is returning of the gravel topping which were removed in the first step.

Renewal of mats was relatively easy to perform, and it takes only few hours total. Hardest part was removing the top gravel because mats need to get out intact and there was no certainty how much gravel layers were deformed during winter and how mats are in between gravel layers. However, after careful excavation the mats were revealed and those remain intact (figure 13).

Figure 12. Mats renewal process on going (Feasib 10.5.2022).

Figure 13. Used old mat after removing of top gravel on the left and new mat on the right, and pilot running in picture on under (Feasib 10.5.2022 and 30.5.2022).

4.3 Follow-up results

For the batch leashing test there was collected 8 sample pieces from each ponds mats which makes total 16 pieces. Each piece was about 100x100 mm. The batch leaching test is performed by Feasib laboratory. The results are showed in table 8.

Table 8. Batch leaching test results compared to waste allocation values (Bold value is the limiting factor).

element/compound	mg/kg dry mass (L/S ≈ 7 l/kg)		threshold value, mg/kg dry mass (L/S = 10 l/kg)		
	Mat 1 (average from 8 samples)	Mat 2 (average from 8 samples)	Inert waste	ordinary waste	Hazardous waste
Arsenic (As)			0,5	2	25
Barium (Ba)			20	100	300
Cadmium (Cd)			0,04	1	5
Total Chromium (Cr_{tot})			0,5	10	70
Copper (Cu)	0,51	0,06	**2**	50	100
Mercury (Hg)			0,01	0,2	2
Molybdenum (Mo)			0,5	10	30
Nickel (Ni)	7,79	0,41	0,4	**10**	40
Lead (Pb)	0,18	0,06	**0,5**	10	50
Antimony (Sb)			0,06	0,7	5
Selene (Se)			0,1	0,5	7
Zink (Zn)	1,03	0,04	**4**	50	200
Chloride (Cl^-)			800	15 000	25 000
Fluoride (F^-)			10	150	500
Sulphate (SO_4^{2-})	3050	1800	1 000	**20 000**	50 000
Phenol index			1		

Results shows that the mats can be disposed as ordinary waste. It needs to note that there are a lot of other elements in Finland's waste classification system which solubility remains unknown in this research. Based on the results it seems that mat from the second pond was released less contaminants than first pond. That may be result from that the first ponds mats fabric collected more suspended solids, and in the batch leaching test these suspended soils releases metals, but adsorbed metals are still remained in the mats adsorbent. Suspended solids were mainly sticked in the first ponds mat and therefore there were lesser soluble metals in the second mats leaching test results.

Previously performed monitoring result is presented in report *B1 final technical report of piloting*. The first test phase sampling started 24.8.2022 and last sample were taken on 21.12.2021. Mats renewing date were 10.5.2022. The second test phase sampling with new mats started 16.5.2022 and stopped 16.8.2022. New mats' combined performance was followed three months and it's compared in following figures 14, 15 and 16 to the first test phase mats combined performance.

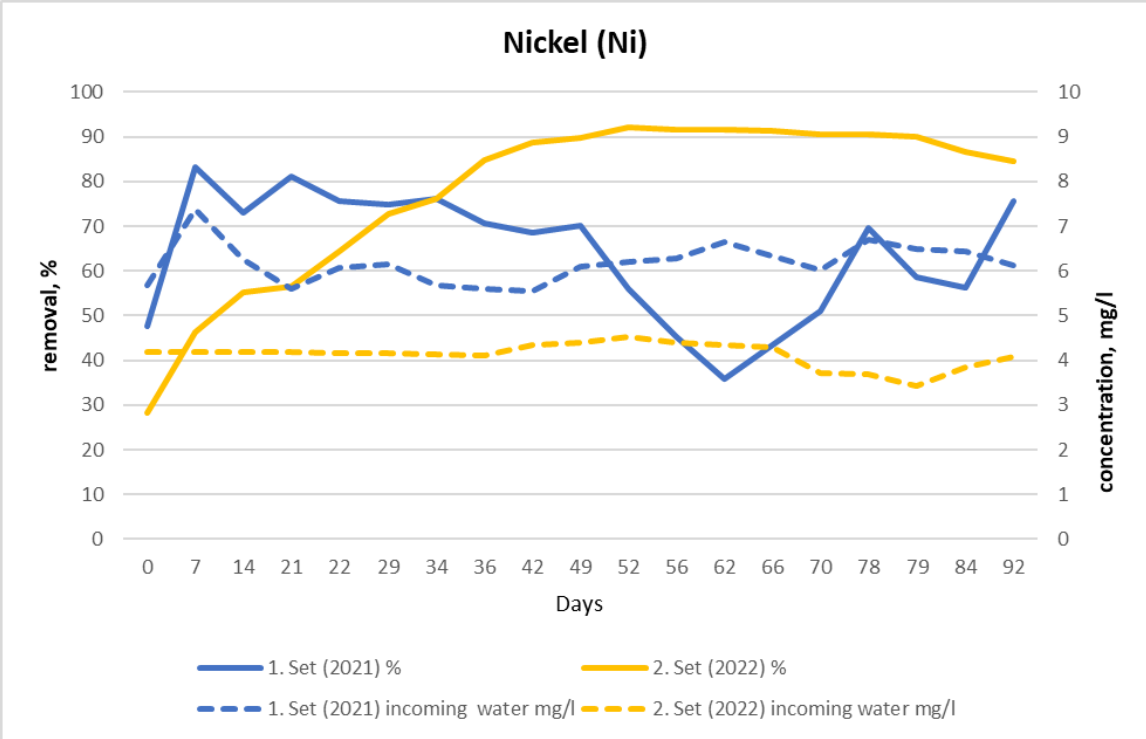


Figure 14. Nickel removal and concentration in inflow water during test periods.

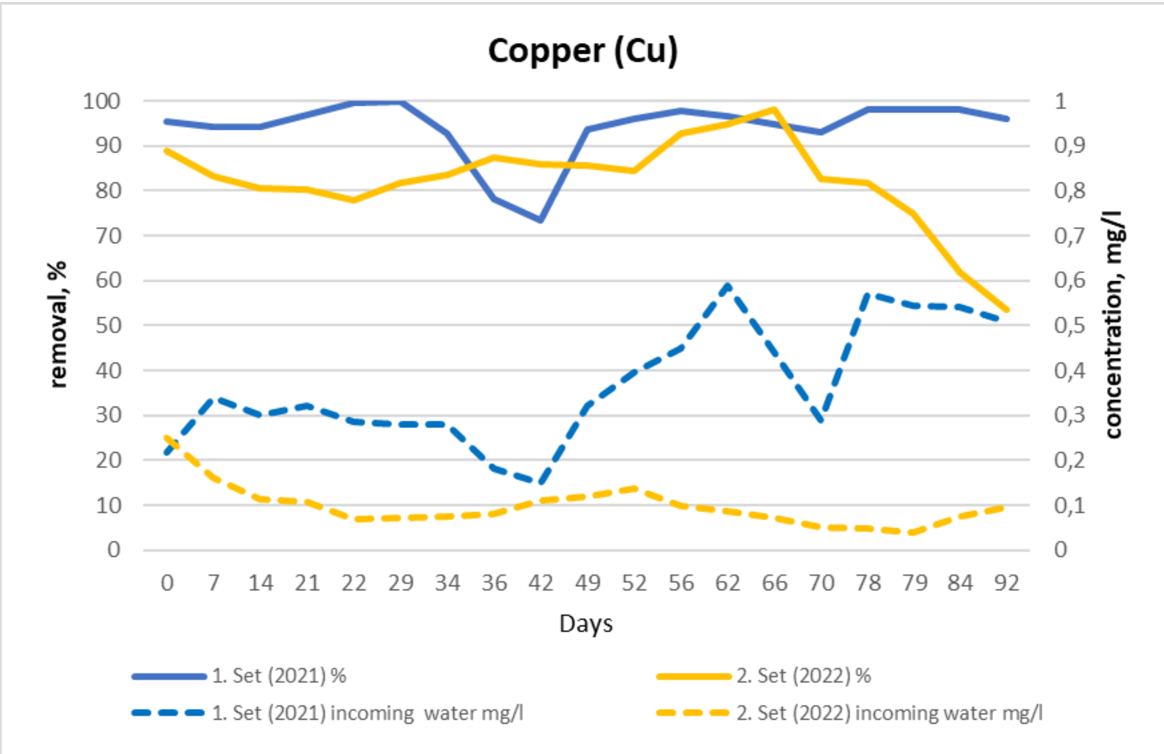


Figure 15. Copper removal and concentration in inflow water during test periods.

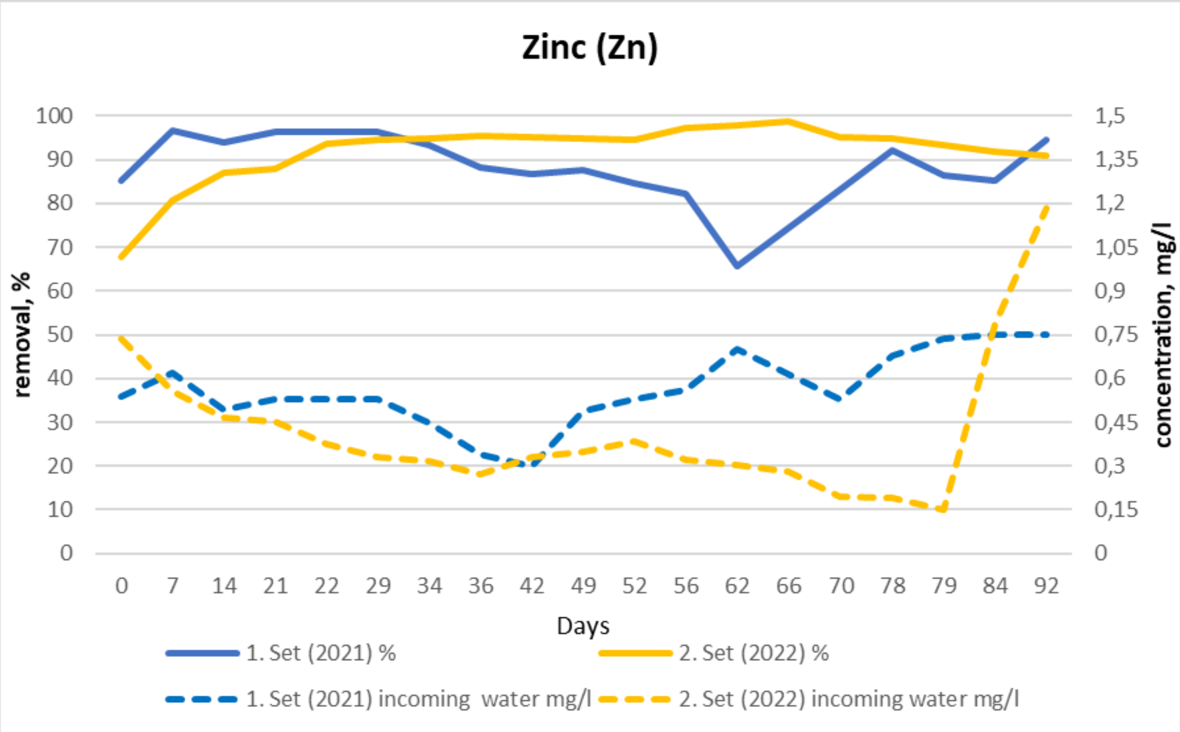


Figure 16. Zinc removal and concentration in inflow water during test periods.

Based on figure's 14-16 comparisons of the pilot structures, mats can be renewed and after that system works as intended, since the removal effectiveness is at the same level than with previous set of mats. After two months monitoring the new mats performance doesn't decreases as the first set were. That is result from lower concentrations in incoming water, as can see from the figure 14, nickel concentration was almost 2 mg/l lower during the second test phase, so the mats' adsorption capacity wasn't used at same rate than in the first test phase. Based on the nickel removal rate mats in second test phase works better than mats in the first test phase, since the removal rate is more stable and surpass the previous one after 34 days. Lower removal rate at the start may be result from mobilization of suspended solids on mat renewal operation.

Other metals concentrations were low in incoming water, so normal uncertainty of measurement may have been impacted to the results. Based on the figure 15 there can be noted degradation in the copper removal rate in second test phase, but concentration in incoming water was quite low <0,1 mg/l, which may affect to removal rate.

In the figure 16, zinc removal rate was in good level >90 % during the second test phase. In the first test phase there can be noted degradation of the mats, but the concentration in incoming water was also quite low <0,75 mg/l. However, zinc removal rate varies more in the first test phase than the second test phase.

5. QUALITY CONTROL METHODS

5.1 Direct quality control

During construction of fiber clay sealing layer and moraine sealing layer the quality is assured by constant density measuring after each 1000 m^2 of constructed area. Density and water content is measured using Troxler field analyzer. That result is compared to laboratory samples which are prepared from same material and those water permeability, density and water content is known. If field results are at least as good as laboratory samples, it will fulfil the demanded water permeability value $1x10^{-8}$ m/s. This method is used also in vertical sealing barrier structure's quality assurance and control. That structures demanded water permeability value is $1x10^{-9}$ m/s.

Previously mentioned method is conformed to work as well with secondary materials than traditional materials during UPACMIC-project. The conformation is done during building method testing squares. Troxler measuring is fast and doesn't disturb the actual construction because it can be done right after the measured area is finished, such as every 1000 m^2. Then there is not as much working machinery movement than during construction. Limit values based on pre-testing in laboratory, which are determined variation in density level (sensitivity) without affects to the quality in structure.

During fiber clay and moraine sealing layer pilot construction has been done Troxler quality control measurements. There were total 203 measurements and from those 106 were done to moraine, 23 to fiber clay from Oulu, 50 to fiber clay from Äänekoski and 24 to fiber clay from Mänttä. All of those fulfil the demands of structure. Measurements are presented in annex 1. Same kind of quality control measurement has been done for two clay that has been used in barrier of vertical sealing barrier structure in Kuopio. In Kuopio total 66 measurement has been done and from those 46 were done to clay from Hamula and 20 to clay from Mäkelä all those results fulfil the demands. Measurements are presented in annex 2.

5.2 Indirect quality control measurements

UPACMIC-project has started almost decade ago, and monitoring technology has taken big leaps during that time. Constructing environmental sensor network (ESN) was ambitious goal of this project. ESN monitoring method has been left out from UPACMIC-projects scope.

Outside of this project Ramboll has developed data bank system called E-map. E-map combine online monitoring to traditional sampling and bring data to one place automatically from multiple sources. Data can be plotted on map to get more pleasant visual view angle about where the data points are located. In E-map software environment results can be plotted to same graph and compared values against threshold values and other measuring points. Historic data can be attached to e-maps data pool to get more holistic result comparison.

5.3 Comparing quality control methods

Lysimeter is structure which collect seeping water under material layer or layers. Collected water can be tested and results gives qualitative and quantitative information of how material layer or layers affect to the seeping water. Lysimeters dimensions can be designed to fit for usage and location. Lysimeter properties are estimated in SWOT 1.

With construction of test squares, can be tested material handling and different working methods. Also needed work for achieving wanted structural attributes can be determined, to avoid unnecessary extra work. Example how many times fiber clay needs runovers with excavator to match demanded density or if it is even achievable with used method. Another tested variable may be material's optimum water content to achieve best performing structure. Testing squares method is estimated in SWOT 2.

SWOT 1 analysis of lysimeter testing.

	Helpful to achieve the objective	**Harmful** to achieve the objective
Internal origin (attributes of the organization)	**Strengths** -Produces a lot of information from real world test environment. -Used longtime so know-how is remarkable. -Flexible can be scaled up or down.	**Weaknesses** -Needs long monitoring time to settle. -Sampling taking some time. -Need to be well designed to work as intended.
External origin (attributes of the environment)	**Opportunities** -Leaching is often concern and concentrations of metals are under the scope. -May fit for long-time monitoring after construction work.	**Threats** -No standardized method. Each setup is unique. -Often uses rainwater as seeping water so tied to rainfalls. -Cold winter (water freezes) and springs flooding may affect to results and monitoring.

SWOT 2 analysis of construction method testing squares.

	Helpful to achieve the objective	**Harmful** to achieve the objective
Internal origin (attributes of the organization)	**Strengths** -Constructing methods and vehicles usability with tested materials and mixtures can be verified. -Used working method can be calibrated to match to demanded structural quality so unnecessary extra work is avoided. -Flexible can be scaled up or down.	**Weaknesses** -If the assumed working method doesn't work may finding suitable method take time and money. -Test structures may be constructed more careful than real structure afterwards and that may lead overestimated structural performance and costly repairing works afterwards.
External origin (attributes of the environment)	**Opportunities** -Small test structures which prove that those works as intended, can be used on larger structure plan's validation and environmental qualification approval.	**Threats** -No standardized method. Each setup is unique. -Weather conditions at constructing phase may not be ideal which lead wrong conclusions.

Reactive barriers and materials have not tested enough to make sure that those works whole lifespans (no clogging or wash off) and those lifespans is unclear in real applications with real polluted water. Lifespan is calculated mathematically and can be test in laboratory, but final tests needed to be performed in the field. For reactive materials such as reactive barrier and reactive mat is designed pond system for testing them in real world applications. Test setup needs natural height differences for working passively. Passive system is desirable because active systems need electricity which adds up costs in long run. Passive systems can be also work remotely which is also those advantage. That kind of testing set up gives data which is affected by weather conditions and chancing of concentration of incoming water. This setup can be scaled up or down to fit other applications and locations.

Controlled pond test system can be constructed in smaller scale than the designed full scale structure. In the pond system water flows through to the test material, and test material react with hazardous substances. Material' performance can be estimated by monitoring system's incoming and outcoming water properties. Pond test system potential is estimated in SWOT 3.

SWOT 3 analysis of controlled pond test systems for reactive material durability testing.

	Helpful to achieve the objective	**Harmful** to achieve the objective
Internal origin (attributes of the organization)	**Strengths** -Flow can be controlled and stopped when wanted. -Gives real world data from material performance. -More variables than in laboratory which gives more valid data. -Mathematical lifespan can be proven and correct.	**Weaknesses** -If the assumed working method doesn't work may finding suitable method take time and money. -Test structures may be constructed more careful than real structure afterwards and that may lead overestimated structural performance and costly repairing works afterwards.
External origin (attributes of the environment)	**Opportunities** -Small test structures which prove that those works as intended, can be used on larger structure as well. -Tests can be used for material approval and proven environmental friendliness or suitability for tested purpose. -Often passive system is more desirable than active system from client perspective.	**Threats** -Weather conditions during monitoring phase may not be ideal or constant which may lead wrong conclusions. -Extreme weather events may damage systems. -Tested water may not be suitable for materials. -Needs natural height difference for working passively. -Every polluted water is different which effect materials lifespan so case by case designing and applying is necessary.

Troxler meter is a measurement for the density monitoring. When material water permeability is estimated based on water permeability relsults in known density in laboratory. There have been determined a target density, where material fulfil water permeability demands in the structure. By Troxler it's easy to monitor density, which can be use for quality control of the construction work. Troxler meter as quality control equipment is estimated in SWOT 4.

SWOT 4 analysis of Troxler-meter.

	Helpful to achieve the objective	**Harmful** to achieve the objective
Internal origin (attributes of the organization)	**Strengths** -Produces information from density and water content. -Easy and fast way for quality control in construction site during construction work. - Can be used with different materials.	**Weaknesses** -May need laboratory tests before using (reliability). -There must be careful when using it, example ensure flat and clean measuring surface. -Meter causes radiation.
External origin (attributes of the environment	**Opportunities** -Fit for quality control monitoring of structure during construction (density quality control). -Useful in comparing different materials and compacting ways.	**Threats** -Varying results between different users. -Heterogenic materials and grain size will affect to results.

6. IMPACT VERIFICATION

Environmental quality and verification as LCA, LCC and LCIA calculations indicates how well the structures is constructed, and materials are selected as climate friendliness and cost efficient in mind. UPACMIC projects targets were promote utilization of industrial by-products in mines cover, bottom and reactive structures. Utilization of alternative recovered materials reduce need for virgin materials and prevent CO_2-emissions. Acquired results based on the LCA, LCC and LCIA calculations from each pilot structures, which indicates environmental impacts of the real structures. Calculations are also compared to the results when the structures are constructed by traditional virgin materials. All the results verify clearly environmental impacts and cost when traditional materials are replaced by recovered materials. LCA, LCC and LCIA calculations give information also about what can be improved in future projects to achieve even smaller climate and financial impact. There have come out obsticles and difficulties which seems to affect most of the emissions and cost in the construction project. LCA, LCC and LCIA calculations are presented in annex 3.

Based on the results of LCA, LCC and LCIA, recovered materials utilization the most effective difficulty is material production distance from the construction site. Long distances cause cost and emissions when huge transport vehicles drive hudreds of kilometers with full loading. Fiber clay is verified usable material in many kinds of structures, but there are only few production plants. Surplus soils are formed randomly and unpredictable, so them utilization in massive structures need long-term designing and cooperation from many actors.

Waste centers and soil landfills offer lot of different materials which are usable in earth construction. Many kinds of structures inside those places can be constructed easily environmentally friendly and cost effective by recovered and waste materials. Sites near soil landfills are possible to utilize recovered materials, without affects to the cost or emissions in the project.

LCA, LCC and LCIA calculations are important part of the designing sustainable structures in the future. With these calculations different materials could be compared, and it’s easy to demonstrate material choices’ impacts for the project. Waste disposal also cause emissions and cost, which are reduced when waste could be utilized. In the best case there are win-win situation, where producer get rid of waste and constructor get necessary material.

7. CONCLUSION

Quality control is present in every step of construction process. Methods of quality control can vary between materials and applications. In material testing stages it is property testing which can identify material batch that are suitable for utilization. In material testing phase it's important to optimize material' sensibility for variation in properties changing. Changing properties could be for example water content, density, conditions and material mixture's ratio.

Before construction it is necessary to determine the best working methods fit for material, which demanded structural properties are achieved. Test squares were useful for working method testing and materials workability assurances. Test squares can be constructed in smaller scale in construction site and method fit for example to clarify how weather affect to the construction work.

Quality control during construction ensure uniform structure. Troxler was conformed to be reliable quality control method for monitoring material layers water permeability. Troxler doesn't directly measure permeability, but with calibration for each material it can be used. It is suitable measurement also for the recovered materials. After construction is finished, quality control continues in for of follow-up. Follow-up may lead maintenance works which need again quality control. Long-term follow-up gives important knowledge for the new kind of structures for future. It's important to make sure, that new materials works also in long-term period.

Based on the LCIA, LCA and LCC calculations, new materials possibilities and viability of industrial by-products and surplus soils in mine environment could reduce emission, energy usage and depletion of natural resources. Material sources need to be close to achieve the best results. There have also found benefits of using new materials like better quality and properties conservation in the structure than traditional materials. Calculations are checked by two specialists from Aalto University.

There are many sustainable development goals in nowadays, which means lower carbon dioxide emissions and natural resources reducing, energy efficiency etc. All those targets push also mining sector to make the action more sustainable, which means minimizing environmental impacts and large areas utilizing in future after mining. In UPACMIC project have been presented many options for different cover structures' materials, which are sustainable and could replace traditional virgin materials. Mining sector cover structures need a lot of material, when virgin material can be replacsed by waste or by-products, it is a huge step toward more sustainable mining.

Annex 1

Moreeni

tavoite KT 1985

		DD	WD	%M	Ero mitattu-tavoite
21.touko	1	1985	2077	6,9 %	0
21.touko	2	1999	2099	8,7 %	14
21.touko	3	1986	2071	4,9 %	1
21.touko	4	1991	2089	7,3 %	6
21.touko	5	1996	2070	7,2 %	11
21.touko	6	1997	2091	4,0 %	12
21.touko	7	2020	2101	6,9 %	35
22.touko	8	2011	2098	7,5 %	26
22.touko	9	2012	2106	8,3 %	27
22.touko	10	2000	2060	7,5 %	15
22.touko	11	1990	2050	9,2 %	5
23.touko	12	2052	2150	8,2 %	67
23.touko	13	2071	2191	8,1 %	86
23.touko	14	2008	2089	6,8 %	23
23.touko	15	2052	2172	5,8 %	67
23.touko	16	2027	2157	6,4 %	42
23.touko	17	2032	2171	6,8 %	47
23.touko	18	2035	2173	6,8 %	50
23.touko	19	1994	2137	7,3 %	9
24.touko	20	2010	2149	6,9 %	25
24.touko	21	2004	2091	7,0 %	19
24.touko	22	2018	2151	6,6 %	33
24.touko	23	2027	2155	6,4 %	42
24.touko	24	1993	2148	7,8 %	8
24.touko	25	1998	2149	7,5 %	13
24.touko	26	1990	2091	7,2 %	5
25.touko	27	1990	2080	6,9 %	5
25.touko	28	1997	2077	6,8 %	12
25.touko	29	2006	2107	5,0 %	21
25.touko	30	1998	2082	6,8 %	13
25.touko	31	2084	2164	5,0 %	99
25.touko	32	1998	2081	8,9 %	13
28.touko	33	2000	2170	8,9 %	15
28.touko	34	2011	2119	8,9 %	26
28.touko	35	1997	2101	9,9 %	12
28.touko	36	2021	2191	9,8 %	36
28.touko	37	2031	2181	9,1 %	46
28.touko	38	2002	2075	8,1 %	17
28.touko	39	1999	2084	9,0 %	14
28.touko	40	1997	2101	9,9 %	12
28.touko	41	1990	2099	10,5 %	5
28.touko	42	2021	2191	8,7 %	36
29.touko	43	2021	2131	9,8 %	36
29.touko	44	2014	2141	8,1 %	29
29.touko	45	2014	2141	8,1 %	29
29.touko	46	2009	2151	8,7 %	24
29.touko	47	2007	2081	8,6 %	22
29.touko	48	2006	2075	9,9 %	21
29.touko	49	2026	2099	9,7 %	41
29.touko	50	2038	2087	9,6 %	53
29.touko	51	2041	2166	9,5 %	56
29.touko	52	2044	2198	8,3 %	59
29.touko	53	2092	2100	8,7 %	107
29.touko	54	2040	2119	9,6 %	55
29.touko	55	1991	2068	10,0 %	6
29.touko	56	2011	2078	9,1 %	26
29.touko	57	2001	2051	8,8 %	16
30.touko	58	1997	2095	9,7 %	12
30.touko	59	1991	2163	7,4 %	6
30.touko	60	1996	2069	9,6 %	11
30.touko	61	2005	2111	9,1 %	20
30.touko	62	2002	2100	8,7 %	17
30.touko	63	1990	2146	8,6 %	5
30.touko	64	2044	2211	8,2 %	59
30.touko	65	2060	2229	8,2 %	75
30.touko	66	2010	2146	7,0 %	25
30.touko	67	2000	2111	9,9 %	15
30.touko	68	1988	2131	7,2 %	3
30.touko	69	1999	2159	6,9 %	14
30.touko	70	1992	2180	6,8 %	7
30.touko	71	1999	2047	10,6 %	14
30.touko	72	1998	2077	10,9 %	13
30.touko	73	1997	2089	9,8 %	12
30.touko	74	1989	2081	8,1 %	4
31.touko	75	1989	2066	8,7 %	4
31.touko	76	1997	2071	8,5 %	12
31.touko	77	1999	2069	8,1 %	14
31.touko	78	1998	2091	8,9 %	13
31.touko	79	2001	2064	9,1 %	16
31.touko	80	2010	2094	8,7 %	25
31.touko	81	2021	2099	9,1 %	36
31.touko	82	2017	2111	8,4 %	32
31.touko	83	1988	2076	9,0 %	3
31.touko	84	1993	2053	8,4 %	8
1.kesä	85	2019	2173	9,0 %	34
1.kesä	86	2028	2156	8,7 %	43
1.kesä	87	2003	2079	8,3 %	18
1.kesä	88	2014	2114	8,6 %	29
1.kesä	89	2003	2047	9,9 %	18
6.kesä	90	2011	2057	9,6 %	26
6.kesä	91	1989	2066	8,4 %	4
6.kesä	92	1994	2075	9,8 %	9
6.kesä	93	2045	2068	9,1 %	60
6.kesä	94	1992	2091	8,3 %	7
12.kesä	95	2004	2054	8,2 %	19
12.kesä	96	2001	2068	8,1 %	16
12.kesä	97	2000	2101	8,9 %	15
12.kesä	98	2025	2210	9,9 %	40
12.kesä	99	2041	2074	9,0 %	56
12.kesä	100	1989	2093	8,4 %	4
12.kesä	101	2004	2081	8,1 %	19
18.kesä	102	2008	2075	8,4 %	23
18.kesä	103	2009	2078	8,4 %	24
18.kesä	104	1985	2077	6,9 %	0
18.kesä	105	1999	2099	5,8 %	14
18.kesä	106	1986	2071	4,0 %	1

OPA Sakka Oulu

tavoite KT 860

		DD	WD	%M	ero mitattu-tavoite
23.touko	1	1038	1405	65,4 %	178
24.touko	2	1000	1371	61,8 %	140
24.touko	3	867	1439	65,8 %	7
24.touko	4	869	1449	66,7 %	9
24.touko	5	919	1462	59,1 %	59
24.touko	6	998	1344	64,4 %	138
24.touko	7	872	1440	65,2 %	12
24.touko	8	968	1465	51,4 %	108
25.touko	9	910	1456	60,0 %	50
25.touko	10	999	1321	63,8 %	139
25.touko	11	896	1464	63,4 %	36
25.touko	12	991	1346	66,9 %	131
29.touko	13	1111	1500	72,9 %	251
30.touko	14	901	1437	59,5 %	41
30.touko	15	914	1501	64,3 %	54
1.kesä	16	1087	1467	69,4 %	227
1.kesä	17	990	1299	62,4 %	130
1.kesä	18	1061	1399	64,9 %	201
1.kesä	19	1042	1411	63,9 %	182
6.kesä	20	1010	1400	69,4 %	150
6.kesä	21	1001	1397	61,9 %	141
6.kesä	22	993	1401	60,4 %	133
6.kesä	23	1002	1491	60,5 %	142

Äänekosken kuitusavi

tavoite KT 458

		DD	WD	%M	ero mitattu-tavoite
23.touko	1	484	1260	160,5 %	26
23.touko	2	470	1259	168,0 %	12
23.touko	3	461	1254	172,0 %	3
24.touko	7	546	1333	143,9 %	88
24.touko	8	508	1333	161,7 %	50
24.touko	9	526	1343	153,4 %	68
25.touko	10	548	1441	154,2 %	90
25.touko	11	531	1344	152,8 %	73
25.touko	12	573	1355	140,0 %	115
29.touko	13	559	1369	145,0 %	101
29.touko	14	581	1403	141,4 %	123
29.touko	15	627	1440	130,0 %	169
30.touko	16	631	1435	127,0 %	173
30.touko	17	782	1528	95,5 %	324
30.touko	18	829	1562	88,5 %	371
30.touko	19	891	1538	84,0 %	433
30.touko	20	882	1642	86,3 %	424
4.kesä	21	523	1246	141,8 %	65
4.kesä	22	505	1239	145,2 %	47
4.kesä	23	478	1255	160,5 %	20
4.kesä	24	515	1221	159,5 %	57
12.kesä	25	510	1250	141,5 %	52
12.kesä	26	471	1240	157,0 %	13
12.kesä	27	480	1210	150,0 %	22
12.kesä	28	460	1199	159,8 %	2
12.kesä	29	579	1245	141,9 %	121
12.kesä	30	499	1231	144,4 %	41
12.kesä	31	547	1245	147,7 %	89
12.kesä	32	509	1240	144,5 %	51
12.kesä	33	511	1255	143,3 %	53
12.kesä	34	497	1246	146,0 %	39
14.kesä	35	506	1246	140,0 %	48
14.kesä	36	529	1249	143,0 %	71
14.kesä	37	500	1239	144,2 %	42
14.kesä	38	501	1227	151,6 %	43
14.kesä	39	508	1229	147,7 %	50
18.kesä	40	498	1239	142,6 %	40
18.kesä	41	513	1245	155,5 %	55
18.kesä	42	477	1237	159,8 %	19
18.kesä	43	458	1227	144,7 %	0
18.kesä	44	479	1239	140,0 %	21
18.kesä	45	519	1246	144,8 %	61
18.kesä	46	507	1236	140,1 %	49
20.kesä	47	554	1210	144,8 %	96
20.kesä	48	508	1239	154,2 %	50
20.kesä	49	497	1244	150,0 %	39
20.kesä	50	481	1246	144,8 %	23

Mäntän kuitusavi

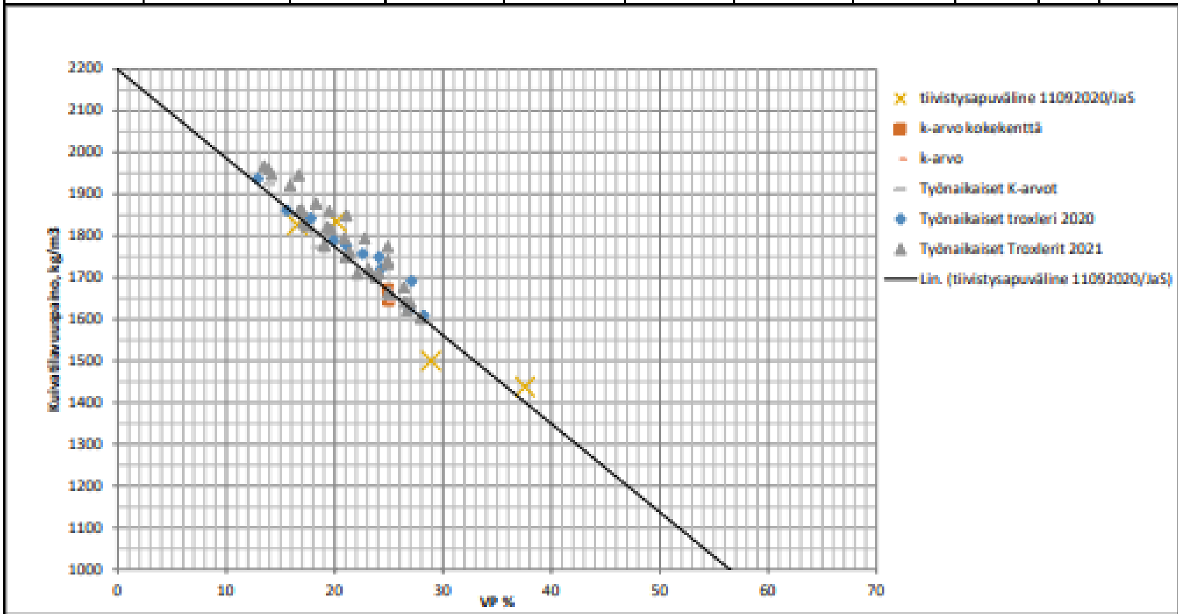
tavoite KT 445

		DD	WD	%M	ero mitattu-tavoite
24.touko	1	482	1157	140,3 %	37
24.touko	2	457	1153	152,3 %	12
24.touko	3	456	1167	150,7 %	11
24.touko	4	536	1162	164,5 %	91
24.touko	5	500	1101	164,8 %	55
24.touko	6	564	1221	162,4 %	119
24.touko	7	521	1122	154,4 %	76
25.touko	8	450	1162	157,9 %	5
25.touko	9	468	1156	144,0 %	23
25.touko	10	561	1155	156,0 %	116
25.touko	11	486	1168	140,3 %	41
25.touko	12	478	1160	154,8 %	33
29.touko	13	458	1162	148,8 %	13
29.touko	14	474	1143	149,0 %	29
29.touko	15	485	1160	144,0 %	40
29.touko	16	538	1166	147,5 %	93
30.touko	17	459	1163	163,4 %	14
30.touko	18	473	1157	145,4 %	28
30.touko	19	483	1161	149,0 %	38
30.touko	20	511	1119	164,2 %	66
4.kesä	21	522	1164	143,8 %	77
4.kesä	22	511	1149	141,4 %	66
4.kesä	23	531	1158	140,9 %	86
4.kesä	24	530	1168	150,1 %	85

Annex 2

Fortum Waste Solutions Oy, Sorsasalon teollisuusjätekeskus						4.10.2021
Pystyeriste TavOm-VJ 2020-21						
Troxlerit, Hamulan savi						

Tiivistysapuväline 11092020/JaS					
		ominaisuudet k-arvo mittauksen jälkeen			
Näytenumero	Näytteen nimi	VP [%]	MT [kg/m3]	KT [kg/m3]	k-arvo
13KA00319	Vanha savi kasa 1	37,6	1978,9	1438,1	1,8E-10
13KA00321	Vanha savi kasa 3	16,6	2129,8	1826,6	9,3E-10
13KA00322	Vanha savi kasa 4	20,2	2205,1	1834,5	9,8E-10
14KA00243	Hamula /M.Hartika	28,92	1934,3	1500,6	3,2E-10
T11	k-arvo	24,9	2087,0	1671	7,30E-10
N2	k-arvo 20KA00406	25	2056,0	1645	9,90E-10



Työnaikaiset mittaukset

K-arvot 2020-21

PVM	Näyte	Määrä	DD	WD	VP%	K-arvo
7.12.	20KA00484	5000 tn	1809,4	2140,5	18,3	5,00E-10
	20KA00485	6000 tn	1772,4	2098,4	18,4	8,50E-10
	20KA00486	7000 tn	1806,1	2136,7	18,3	4,10E-10
28.1.2021	21KA00019	8000 tn	1650,4	2063	25	5,10E-10
	21KA00020	9000 tn	1924,7	2194,2	14	2,90E-10
2.7.2021	21KA00218	6000 m3	1937,7	2255,5	16,4	4,50E-10

Troxlerit 2020-21

PVM	Piste	Syvyys	DD	WD	VP%	Kerros
17.11.2020	30	150	1757	2151	22,6	1. kerros
		300	1749	2170	24,1	
	31	150	1691	2149	27,1	
		300	1776	2149	21,1	
18.11.2020	32	150	1937	2186	12,9	
		300	1861	2150	15,6	
23.11.2020	33	150	1609	2062	28,2	2.kerros
		300	1621	2057	26,9	
24.11.2020	34	150	1721	2139	24,3	
		300	1789	2145	19,9	
25.11.2020	35	150	1842	2169	17,8	3.kerros
		300	1839	2163	17,6	
20.5.2021	36	150	1641	2075	26,5	1.kerros
		300	1602	2049	27,9	
	37	150	1710	2122	24,1	
		300	1817	2173	19,6	
21.5.2021	38	150	1849	2239	21,1	2.kerros

		300	1921	2226	15,9					
24.5.2021	39	150	1947	2224	14,2	3.kerros				
		300	1946	2270	16,7					
14.6.2021	40	150	1861	2177	17,0	1.kerros				
		300	1821	2172	19,3					
		300	1794	2203	22,8					
15.6.2022	41	150	1776	2115	19,1	2.kerros				
		300	1701	2105	23,8					
16.6.2021	42	150	1774	2215	24,9	3. kerros				
		300	1721	2118	23,1					
22.6.2021	43	150	1741	2174	24,9	4.kerros				
		300	1640	2089	27,0					
23.6.2021	44	150	1666	2089	25,0					
		300	1831	2144	17,1					
3.8.2021	45	150	1859	2221	19,5	5.kerros				
		300	1967	2233	13,5					
	46	150	1960	2232	13,9					
		300	1824	2141	17,4					
5.8.2021	47	150	1860	2170	16,7	6. kerros				
		300	1878	2219	18,3					
9.8.2021	48	150	1794	2169	20,9					
		300	1710	2110	23,4					
12.8.2021	49	150	1734	2166	24,9	7.kerros				
		300	1709	2087	22,1					
13.8.2021	50	150	1776	2113	19,0					
		300	1750	2117	21,0					
16.8.2021	51	150	1762	2139	21,4	8. kerros				
		300	1661	2078	25,1					
17.8.2021	52	150	1677	2199	26,4					
		300	1621	2054	26,7					

Troxlerit Mäkelän savi

Fortum Waste Solutions, Sorsasalon teollisuusjätekeskus							19.12.2020
Pystyeristys TavOm-VJ 2020-21							
Tiivistyskerroksen Troxler-mittaukset							
Koekenttä							
	PVM	PISTE	SYVYYS	KT	MT	VP%	
	7.10.	11	300	1264	1750	38,5	
			250	1304	1791	37,3	
			200	1292	1793	38,8	
			150	1318	1787	35,6	
			100	1313	1780	35,6	
			50	1196	1734	44,4	
	7.10.	12	300	1268	1739	37,2	
			250	1312	1752	33,5	
			200	1295	1745	34,8	
			150	1314	1775	35,1	
			100	1322	1787	35,2	
			50	1306	1791	37,1	
	7.10.	13	300	1304	1776	36,1	
			250	1281	1750	36,6	
			200	1301	1779	36,7	
			150	1309	1783	36,2	
			100	1256	1768	40,7	
			50	1322	1783	34,9	
	7.10.	14	300	1208	1697	40,4	
			250	1220	1698	39,2	
			200	1193	1682	40,9	
			150	1156	1664	43,9	
			100	1163	1652	42,0	
			50	1163	1600	42,7	
	7.10.	15	300	1228	1740	41,7	
			250	1232	1750	42,1	
			200	1239	1734	39,9	
			150	1190	1726	45,0	
			100	1141	1693	48,8	
			50	1174	1699	44,7	
Työnaikaiset mittaukset 2020							
	15.10.	20	300	1310	1789	36,6	
			150	1232	1729	40,4	
	15.10.	21	300	1241	1735	39,9	
			150	1230	1723	40,1	

	20.10.	22	300	1301	1805	38,8	
			150	1314	1775	35,1	
	21.10.	23	300	1311	1804	37,7	
			150	1230	1708	39,0	
	29.10.	24	300	1237	1720	39,1	
			150	1292	1784	38,1	
	3.11.	25	300	1355	1830	35,1	
			150	1289	1780	38,1	
	5.11.	26	300	1379	1885	36,7	
			150	1313	1807	37,7	
		27	300	1300	1766	35,9	
			150	1220	1694	38,9	
	9.11.	28	300	1304	1787	37,1	
			150	1232	1726	40,1	
		29	300	1219	1693	39,0	
			150	1323	1811	36,9	

Annex 3

LIFE12 ENV/FI/000592

ENVIRONMENTAL IMPACT

LCA/LCC/LCIA CALCULATION

LIFE12 ENV/FI/000592 UPACMIC

ENVIRONMENTAL IMPACT

Project name	**UPACMIC**
Project no	**151006900-012**
Date	**10.8.2022**
Prepared by	**Pyry Potila** **Emmi Ilonen**
Checked by	**Justus Uusi-Viitala**

CONTENT

GLOSSARY OF TERMS

Abiotic material Non-living chemical and physical part of the environment that affect living organisms and the function of ecosystem.

Allocation Sharing of input and output streams of a process or product system between the product system under investigation and one or more other product systems [1].

By-product Secondary product which is produced as side stream from primary production.

Cut-off criteria Specification of the amount of material or energy flow or the level of environmental significance associated with the unit process or product system, to be excluded from the inventory [1].

Functional unit Quantitative performance of a product system used as a reference unit [1].

Environmental aspect The part of an organization's activities, products or services that may interact with the environment [1].

Global warming potential (GWP)
Expresses the relative intensity of the heating effect (radiative forcing) of greenhouse gas emissions over a given time period relative to carbon dioxide unit mass. Its numeric value is expressed as the Global Warming Potential (GWP) coefficient for the most part over a period of 100 years (GWP100) or 20 years (GWP20). For example, the GWP100 factor for methane is 21, which means that the cumulative heating effect of methane emissions over a hundred years is 21 times the effect of carbon dioxide emissions. The heating potential takes into account not only the different thermal transmission characteristics of the gases but also their different residence times in the atmosphere. [4]. This is

estimated using CO_2 equivalent, which is calculated combination of all greenhouse gas emissions which are converted to CO_2 emissions.

Input Product, material or energy flow entering the unit process [1].

Life cycle Successive or interactive stages of the product system from the extraction or production of raw materials from natural resources to final disposal [1].

Life cycle assessment (LCA)
Compiling and evaluating product system life cycle inputs and outputs and potential environmental impacts [1].

Life cycle cost (LCC) Is defined as the cost of an asset or its parts throughout its life cycle while the performance requirements [3].

Life cycle impact assessment (LCIA)
Life cycle assessment phase to understand and evaluate the extent and significance of the potential environmental impacts of a product system throughout the product life cycle [1].

Output Product, material or energy flow leaving the unit process [1].

Product Any good or service [1].

Product system Series of unit processes with elementary streams and product flows that perform one or more specified functions and describe the product life cycle [1].

Unit process The smallest element to take into account in the inventory analysis for which input and output data are defined [1]. Examples of unit processes: material dissemination and sealing.

UPACMIC Utilisation of by-products and alternative construction materials in new mine Construction, LIFE12 ENV/FI/000592

1. INTRODUCTION

Life Cycle Assessment (LCA) is a methodology for assessing environmental impacts of a product, process, or service during its lifetime or over a chosen lifetime period. In the UPACMIC project (Utilisation of by-products and alternative construction materials in new mine Construction, LIFE12 ENV/FI/000592) LCA has been carried out as a simplified version (streamlined LCA). The environmental impact of project pilots is estimated using Life Cycle Impact Assessment (LCIA). The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***. Results are mainly represented using following three units: GHG emissions as kg CO_2 eq, used nonrenewal material consumption as kg and energy consumption as MJ.

The goal of LCIA of piloting is to assess the environmental impacts of the piloted structures and to verify that the pilot alternatives are environmentally more viable option compared to the conventional alternative. The three focused pilot structures were tailing basin cover structure’s sealing layer, vertical sealing barrier and pre-crushing site covering. Materials what is compared were fibre clay from three different location, surplus soils, natural moraine and aggregates. Fibre clay is produced as a residual material in paper recycling process in paper industry. Fibre clay has been used in landfill sealing layers for some time, but now it has been used in the mining environment for the first time. The conventional alternative for the fibre clay is a cover structure made with virgin moraine. Materials which are used in sealing structure in Kuopio were waste or surplus materials. Moraine, gravel and sand are virgin materials and therefore the emissions from the production and depletion if natural resources have been taken into account in the LCIA. All structure’s pilotings are described more detailly in the *B1 Final Technical report on piloting (2022)* .

The sizes of pilot structures were different so for even comparison has been used the functional unit (FU) 1000 m^2 of the cover structure. For the vertical sealing structure the functional unit is 1 m^2 of wall. All calculations are carried out for functional unit area and results are easy to scale up or down to match to full size structures impacts by simple multiplication.

For Life Cycle Cost (LCC) calculations data of work and transport costs were collected from real billings. Prices includes fuel, worker and machine costs. Functional unit is same as in LCIA comparison. The transportation cost of fibre clays is given as €/tonne. For other materials same 2,2 €/km cost of transportation was used. That was the most common pricing during this project. Secondary materials such as fibre clay were calculated as free and only loading work costs. Other material prices were collected and estimated from real billings what has got during the project.

The materials of growth layer are not included in the assessments because they are equal in all structures. Material testing and quality control during material production is not included because the suitability of the materials must be verified for each material. Maintenance and monitoring work is considered to be same for each structure, so it is leaved out from calculation and comparison.

2. UPACMIC PROJECT ENVIRONMENTAL IMPACT

Life Cycle Assessment (LCA) is a methodology for assessing environmental impacts of a product, process, or service during its lifetime or over a chosen lifetime period. The LCA is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system, that can be described as a collection of unit processes which perform one or more defined functions and model the life cycle of the product: e.g. production and manufacturing of construction materials, transportation of materials, preparing the construction site, construction, maintenance and repair.

The LCA consists of a goal and scope definition, an inventory analysis and an impact assessment (Figure 1). On the basis of these stages, interpretation of the results can be made. The LCA results may be useful inputs to a variety of decision-making processes like stated in Figure 1.

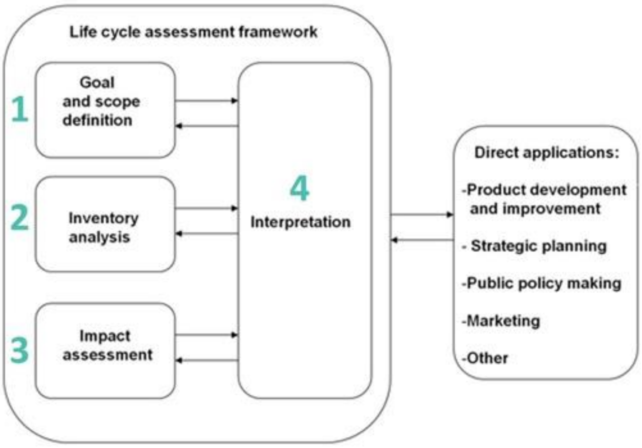


Figure 1. Stages of the life cycle assessment.

The LCA addresses potential environmental impacts. It does not predict *absolute* or *precise* environmental impacts due to the relative expression of potential environmental impacts to a reference unit and due that the environmental data is integrated over space and time.

In the UPACMIC project, LCA methodology is used to assess the environmental impacts of the piloted applications and to compare them with the environmental impacts of a chosen conventional alternative. In the UPACMIC project, LCA was conducted for following pilot structures:

- Fibre clay cover structure piloting in Hitura Mine
- Surplus clay cover structure piloting in Hitura Mine
- Vertical sealing barrier pilot structure in Sorsasalo landfill (in Kuopio)

The LCA methodology is based on the ISO standard (EN ISO 14040:2006). In the UPACMIC project LCA has been carried out as a simplified version (streamlined LCA), where the analysis was limited to the lifecycle phases A1-A3 *product stage* (raw material supply, transport and manufacturing) and A4-5 *construction process* (transport, installation) according to CEN/TC 350 standard EN 15643-5. The analysed structures are permanent and therefore nothing will be done about them after construction. The maintenance and structures monitoring is excluded from LCA comparison.

The environmental impact of project pilots is estimated using Life Cycle Impact Assessment (LCIA). The reason to carry out the LCIA of fibre clay cover structure piloting in Hitura mine is to assess the environmental impacts of the piloted fibre clay cover structures and to verify that the pilot alternatives are environmentally sound compared to the conventional alternative. Fibre clay is produced as a residual material in paper recycling process in paper industry. Fibre clay has been used in landfill sealing layers for some time, but now it has been used in the mining environment for the first time. The conventional alternative for the fibre clay is a cover structure made with virgin moraine. Cover structure piloting in Hitura mine is described in the *B1 Final Technical report on piloting (2022)*.

The software used in LCIA calculations is a Microsoft Excel-based calculation tool. In the calculations the emission data for transport vehicles and working machines is based on the LIPASTO unit emissions database by Technical Research Centre of Finland [2].

The origin of the data used in the calculations and the basis for the calculations are presented in the following paragraphs and Tables 1-4.

Table 1. The data of diesel used in the LCIA analysis [2].

Attribute	Value	Unit
Specific weight	0,824	
Caloric value	43,2	MJ/kg
Energy 1 kWh	3,6	MJ/kg
Abiotic raw material	0,032*	kg/MJ
Density	0,824	kg/dm^3

*Value from *MIPS-laskenta* guide [13]

Abiotic material depletion of diesel is calculated on the basis of values from Table 1 as follows:

energy of 1 liter diesel: 43,2 MJ/kg x 0,824 kg/l = 35,63 MJ/l

→abiotic material consumption /1 liter diesel: 0,032 kg/MJ x 35,63 MJ/l = 1,14 kg/l

This numeric value of abiotic material is used for the calculation of **depletion of natural resources** in processes where diesel fuel is consumed.

Global warming potential (GWP) is calculated directly using factors that gives CO_2 equivalent (kg or g).

The emissions for used vehicles are calculated on the basis of the LIPASTO database developed by the Technical Research Centre of Finland [2] Where data is defined for a typical machine in each working machine category in Finland (in terms of power use and age of fleet). The emissions are calculated as following:

[fuel consumption, l] x [emission factor, g/l] = emission g.

Energy consumptions in different stages are calculated on the basis of the vehicle energy consumption provided by the LIPASTO database [2], or by the energy consumption values from material producers data. The energy consumptions are calculated with following equations for functional unit:

[MJ/km] x [total km/FU] = MJ/FU (vehicles)
[MJ/h] x [h/FU] = MJ/FU (vehicles)
[MJ/tonne] x [tonne/FU] = MJ/FU (materials)

Depletions of natural resources in different stages are calculated on the basis of the need on natural aggregates/materials provided by the data sources or by fuel consumption provided by LIPASTO database [2]. The depletions of natural resources are calculated with following equations:

[g/tonne] x [tonne/FU] = kg/FU (materials)
[kg/l] x [l/FU] = kg/FU (vehicles)

Table 2. Emission data for used vehicle in lading, construction and transport from LIPASTO [2].

Drivable machines, diesel	Average power [kW]	Average load factor [-]	CO_2 eq Emissions [g/kWh]	CO_2 eq g/fuel litre	Consumption [g/kWh]	Energy [MJ/kWh]
Bulldozers	112	0,40	821	2674	258	11
Wheel loaders	94	0,33	828	2673	260	11
Excavators, skid steer	104	0,31	829	2672	261	11
Farm tractors	77	0,31	852	2723	263	11
Dumpers	153	0,30	818	2672	257	11

Machine average power in Table 2 is the average maximum power of machinery. However, most of the time machine is under loaded and uses only fraction of its maximum power. So, in same Table 2 is introduced average load factor which is correcting factor for calculating machines real power usage while working.

Table 3. Factors for calculating transport's LCIA from LIPASTO [2].

Machines	**CO_2 eq [g/km]**		**Fuel consumption [l/100km]**		**Energy [MJ/km]**	
	Empty	fully loaded	Empty	fully loaded	Empty	fully loaded
Earth moving lorry	558	761	23,5	32,1	8,4	11
Full trailer combination	796	1205	33,7	51,1	12	18

Factors in Table 3 are for highway driving. There are also available factors for city driving but those are not used in calculation, because construction sites located in sparsely populated area and transporting routs were mostly highways due to long distances.

When machine is worked its energy usage is calculated using LIPASTO's equation:
[MJ/kWh] x [kW] x [average load factor] = MJ/h
CO_2 eq emission is calculated using LIPASTO's equation and multipliers:
[kWh] x [g/kWh] = emission g

Used moraine is excavated and stored on piles. That excavation work is estimated to produce CO_2 eq emission of 1,57 kg/m^3 [10]. If the material density is unknow the used global constant is 1,5 kg/dm^3.

For virgin crushed rock aggregates the international EPD® system data is used based on NCC Mäntsälä quarry – Ohkola information [12]. Used values are collected to following Table 4. There are several sources of data available about different quarries. Ohkola site is selected because it is just like the site in Kuopio which is used as origin of alternative case aggregates and represents it well. Data can vary lot site by site due to varying crushing methods and energy sources.

Table 4. Virgin crushed aggregates data of Mäntsälä where values are per 1000 kg. [12]

Product names	**Global warming potential total kg CO_2 eq**	**Total use of non-renewable primary energy resources [MJ]**
All-in Rock 0-150	2,6	34
Coarse rock 16/32	3,5	46
Rock Fines 0/3	4,3	58

3. LIFE CYCLE COST IN UPACMIC PILOTS

Life cycle costing (LCC) is based on the standard ISO-15686-5:2008. The assessment is based on the investment calculations of costs of certain product or functional unit during a life cycle. The purpose of the life-cycle costing should be to quantify life-cycle cost (LCC) into decision making process. This method can be used to assess and evaluate the long-term costs of the alternative structure solutions. The general elements of the LCC calculations are provided on the picture below (Figure 2). The results gained from the LCC are highly connected to the basic data received and the defined scope. The information applied in the UPACMIC project is based on the information received from the contractor and Ramboll Luopioinen own expertise. LCC studies is carried out as simplified versions or as streamlined LCC. The costs used here are capital costs (construction work and material costs). Service life of structures are estimated to be identical and the maintenance and renovation costs as well and structures performance is estimated to be same. Those are excluded from UPACMIC LCC calculations and comparison.

Utilization of waste material cut costs of material producer viewpoint, because then there is no landfilling or waste fees. This positive aspect is excluded from LCC calculations but will be crucial to take in account when comparing transportation costs between natural and waste material.

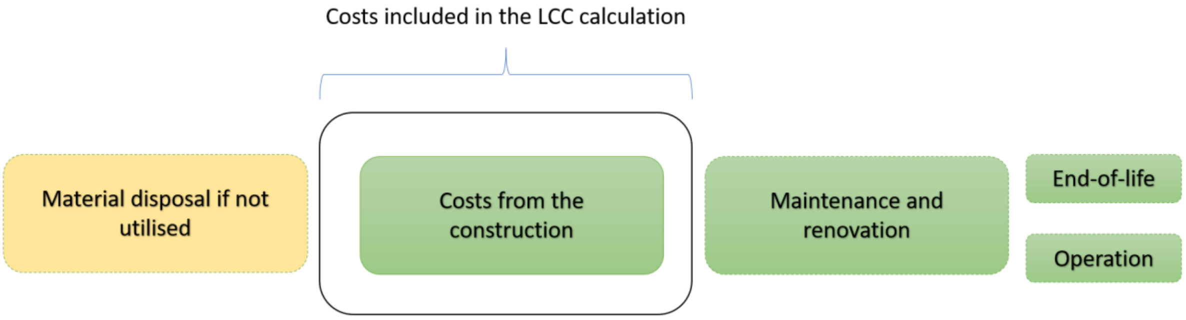


Figure 2: Costs that are included in the life cycle costing.

The purpose of the LCC was to compare the relevant investment costs of the alternatives and to show that the use of surplus soils and secondary materials can be cost-effective.

The LCC's are calculated according to the following sections:

1. Materials
2. Material transportation
3. Construction

LCC's are calculated from same scenarios than LCIA's are done.

4. FIBRE CLAY COVER STRUCTURE PILOTING IN HITURA MINE

The goal and scope of the LCIA

The reason to carry out the LCIA of fibre clay cover structure piloting in Hitura mine is to assess the environmental impacts of the piloted fibre clay cover structures and to verify that the pilot alternatives are environmentally sound compared to the conventional alternative. Fibre clay is produced as a residual material in paper recycling process in paper industry. Fibre clay has been used in landfill sealing layers for some time, but now it has been used in the mining environment for the first time. The conventional alternative for the fibre clay is a cover structure made with virgin moraine. Cover structure piloting in Hitura mine is described in the *B1 Final Technical report on piloting (2022)*.

Figure 3. Fibre clay and moraine cover strictures on top of tailings.

The fibre clay is partly biodegradable which need to take account to maintain layer thickness after some time, but degradation clogs the layer and water permeability decrease. Maintain layer thickness was the reason behind different thickness (200 vs 250 m) of material layers between structures. Fibre clay structure is shown in figure 3. Another benefit of using fibre clay is that it doesn't crack when it dries as natural moraine does. That makes fibre clay sealing layer more durable against weather changes.

The LCIA of fibre clay cover structure piloting in Hitura mine includes four alternative structures. Structure 1 is the conventional alternative, where the cover structure is made of virgin moraine originated from Nivala. Structures 2-4 are made of secondary material of fibre clay originated from three different sites: Mänttä (Structure 2), Oulu (Structure 3) or Äänekoski (Structure 4). Origin of materials is shown in the figure 4.

The total LCIA results of constructed cover layer is compared to alternative case. Alternative fictional case is that pilot site is constructed as in Hitura but the fibre clay producers are closer (50 km each) to the constructing site and source of moraine is further away (37 km).

Table 5. Alternative cover structures compared in the LCIA.

Alternative structure	**Description**
Structure 1	moraine, origin from Nivala
Structure 2	fibre clay, origin from Mänttä (Metsä Tissue)
Structure 3	fibre clay, origin from Oulu (so called "OPA-sakka")
Structure 4	fibre clay, origin from Äänekoski

Figure 4. Origins of fibre clay and moraine.

Table 6. The materials used in the different pilot structure alternatives.

	Material	**Structural thickness [m]**	**Area [m²]**	**Volume [m³]**	**Volume/FU [m³]**	**Density (wet) [kg/m³]**
Structure 1	Moraine	0,2	116242	23 248	200	2070
Structure 2	Fibre clay	0,25	43766	10 942	250	1157
Structure 3	Fibre clay	0,25	56599	14 150	250	1515
Structure 4	Fibre clay	0,25	48485	12 121	250	1182

In 2019 constructed Pilot structures size were different so for even comparison has used the functional unit (FU) 1000 m^2 of the cover structure. All calculations are carried out for functional unit area and results are easy to scale up or down to match to construction area by simple multiplication. The materials of growth layer are not included in the assessment because they are equal in all structures. Material testing and quality control during material production is not included because the suitability of the materials must be verified for each material. Maintenance and monitoring work is considered to be same for each structure, so it is leaved out from calculation and comparison. The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***. Results are mainly represented using following three units: GHG emissions as kg CO_2 eq, used nonrenewal material consumption as kg and energy consumption as MJ.

Material production

Fibre clay is a secondary material from paper industry. Therefore, the environmental impacts related to production of fibre clay have been excluded from the LCIA. The emissions from the production of fibre clay have been allocated to the previous process (the process from which the by-product originates). Only the emissions from loading of fibre clay add emissions and energy usage to material production phase for fibre clay.

The emissions of virgin moraine used in structure alternative 1 include the excavation of moraine and its loading. The CO_2 eq emission moraine excavation is 1,57 kg/m^3 [10]. The loading work hours per loaded m^3 of moraine is 0,012 h/m^3 [11]. For fibre clay that is estimated to be 0,005 h/m^3 because material can be loaded with much higher rate using bigger bucket because fibre clay is lighter than moraine.

Transportation

Moraine is mainly transported by cassette trucks (full trailer combination) and fibre clay is transported by truck combinations. Transportation vehicles payloads are same (40 tonne) so full trailer combinations data values are used in both vehicles. In the calculations LIPASTO data [2] for full trailer combination (Gross vehicle mass 60 t, pay load capacity 40 t) was used, since this option is assumed to be the most descriptive for both transport options. All trucks and working machines are assumed to use same diesel as fuel since it has not been considered essential to study different fuels for every machine or truck. The data used for diesel fuel in the LCIA calculations is based on the LIPASTO data [2] which is shown in Table 1.

Table 7. Transportation distances and driven kilometers.

	Material	Distance to Hitura mine [km]	Driven kilometers/FU [km]
Structure 1 (Nivala)	Moraine	16	166
Structure 2 (Mänttä)	Fibre clay	282	2039
Structure 3 (Oulu)	Fibre clay	167	1581
Structure 4 (Äänekoski)	Fibre clay	176	1300

Construction

The thickness of the piloted cover structure 1 (moraine) was 0,2 m, where the thickness of piloted fibre clay cover structures (alternatives 2-4) was 0,25 m. The fibre clay is partly biodegradable which need to take account to maintain layer thickness after some time, but degradation Glogs the layer and water permeability decreases. Maintaining the layer thickness is the reason behind different thicknesses (200 vs 250 mm) of material layers between structures.

The construction stages and vehicles used in the construction process were supposed to be similar for all alternative structures (Table 8). The construction of the cover structure started with spreading the material (moraine / fibre clay) roughly with a bulldozer and after that the spreading was finalized with skid steer excavator. After spreading, the compacting was done with a skid steer excavator by running over the structure 3 times. In calculations it was assumed that the width of tracs of excavator are 800 mm, which means that 1 600 mm is compacted at a time. It was also assumed that the average speed of excavator was 5 km/h. For one FU unit (1000 m^2) that means that excavator drives 1,875 km and it takes 22,5 min. Average loading factor of excavator is estimated to be 0,5 during the compaction task, because the excavator has to continuously move and turn.

The first compaction overrun is harder than the others, because excavator sinks more into the uncompressed clay.

Table 8. The construction stages and used working machines.

Stage	**Working machine**
Coarse spreading of the material	Bulldozer
Spreading of the material	Excavators, skid steer
Compacting	Excavators, skid steer

Results

The climate impacts of the fibre clay cover structure alternatives are presented in Table 9.

Table 9. Results of the GHG emission per FU of fibre clay cover structure piloting in Hitura mine.

	Materials [kg CO_2 eq]	**Transportation** [kg CO_2 eq]	**Construction** [kg CO_2 eq]	**Total emissions** [kg CO_2 eq]	**Total emissions per tonne of material** [kgCO_2 eq/tonne]
Structure 1 Moraine (Nivala)	375	332	293	1000	2,41
Structure 2 Fibre clay (Mänttä)	32,0	4 082	362	4 4	15,47
Structure 3 Fibre clay (Oulu)	32,0	3 166	362	3 559	9,40
Structure 4 Fibre clay (Äänekoski)	32,0	2 603	362	2 997	10,14

Energy consumption is estimated from calculated diesel fuel usage by power usage using Lipasto databank's values. This approach is selected because there is no real fuel consumption data from transportation and construction.

Table 10. Results of the energy consumption per FU of fibre clay cover structure in Hitura mine.

	Materials [MJ]	**Transportation** [MJ]	**Construction** [MJ]	**Total energy consumption** [MJ]	**Total consumption per tonne of material** [MJ/tonne]
Structure 1 Moraine (Nivala)	2 514	5 004	3 951	11 469	27,70
Structure 2 Fibre clay (Mänttä)	1 310	61 616	4 884	67 811	234,44
Structure 3 Fibre clay (Oulu)	1 310	47 780	4 884	53 974	142,51
Structure 4 Fibre clay (Äänekoski)	1 310	39 286	4 884	45 481	153,91

Depletion of natural resources includes only fuel consumption of machinery with fibre clay. The depletion of natural moraine sources was taken into account, using direct calculation mass to mass. Moraine consumption is about 414 tonne per FU which is about 200 times higher. In Table 11 is presented inside brackets the fuel consumptions part of depletion of natural resources of moraine loading and total amount without moraine to illustrate how much moraines affect to depletion of natural resources.

Table 11. Results of the depletion of natural resources per FU of cover structure in Hitura mine.

	Materials [kg]	**Transportation** [kg]	**Construction** [kg]	**Total** [kg]	**Total per tonne of material** [kg/tonne]
Structure 1 Moraine (Nivala)	414 027 (27)	160	127	414 314 (314)	1000,76 (0,76)
Structure 2 Fibre clay (Mänttä)	14	1 972	157	2 143	7,41
Structure 3 Fibre clay (Oulu)	14	1 529	157	1 700	4,49
Structure 4 Fibre clay (Äänekoski)	14	1 257	157	1 428	4,83

Summary

The transportation causes most of the emission, so the fibre clay structures have the highest emissions (Table 9 and Figure 5). However, if the transport distance would be the same for all alternatives, would the emissions of fibre clay structures be smaller than moraine.

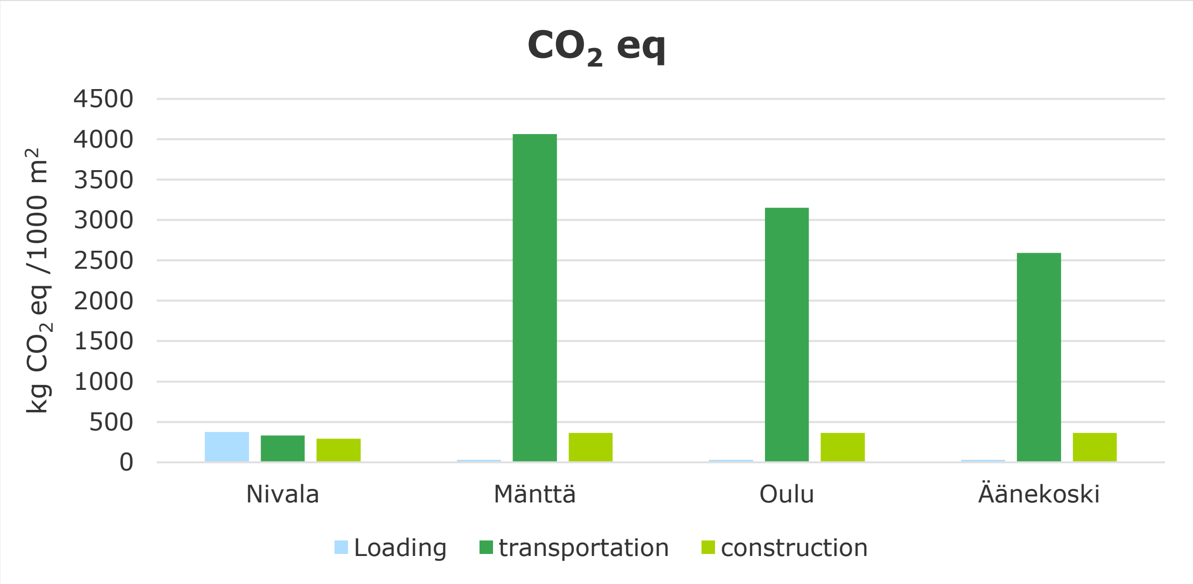


Figure 5. Results of the GHG emission per FU of of fibre clay and moraine cover structure piloting.

As the figure 5 indicates that utilization of fibre clay from Mänttä has app. 4,5 times greater emissions compared to moraine from Nivala and from Oulu and Äänekoski app. 3 times greater. The advantage of using fibre clay is basically zero production emissions, because it is a by-product from industrial production. Therefore, it is good to consider the transport distance while utilizing by-products, because transportation can cause much higher emissions as in this case.

4.1 Life Cycle Cost of fibre clay structures

For LCC calculations data of work and transport costs were collected from real billings. Prices includes fuel, worker and machine costs. Functional unit is again 1000 m^2. The transportation cost of fibre clay is given as €/tonne which is different in Mänttä and Oulu. For Äänekoski there was no transportation cost available, so it was estimated to be same as Oulu's because distance difference was only 9 km. For other road transportations a constant factor 2,2 €/km was used, this was the most common price during this project. Secondary materials such as fibre clay were calculated as free and only loading costed.

Table 12. Work costs of used machinery.

Working machine	€/h
Wheel loader	65
Bulldozer	90
Excavator, skid steer	75

Transportation costs were calculated for functional unit with 2 methods. First is total km/FU x €/km =€/FU and second is mass/FU x €/tonne = €/FU. Used values are in Table 13.

Table 13. Transportation costs.

	€/km	€/tonne
Moraine	2,2	
Fiber clay Mänttä		16,4
Fiber clay Oulu		13,9
Fiber clay Äänekoski		13,9

Only moraine was bought with the price of 5,05 €/tonne, fibre clays were free. Loading work costs on producing facility was calculated based on hours per functional unit.

For easier comparison costs were first calculated per functional unit 1000 m^2 (Table 14). Then costs were scaled to real construction areas and results are presented in Table 15. Figure 6 illustrates the total costs of all structures in every phase.

Table 14. Cost dividing during construction per FU.

	Material [€/FU]	Loading [€/FU]	Transportation [€/FU]	Construction [€/FU]	Total [€/FU]
Moraine Nivala	2091	156	364	754	3365
Fibre clay Mänttä	0	81	4744	936	5761
Fibre clay Oulu	0	81	5265	936	6282
Fibre clay Äänekoski	0	81	4107	936	5124

Table 15. Total cost dividing during construction.

	Material [€]	Loading [€]	Transportation [€]	Construction [€]	Total [€]
Moraine Nivala	243 027	18 134	42 349	87 661	391 171
Fibre clay Mänttä	0	3 556	207 613	40 949	252 117
Fibre clay Oulu	0	4 599	297 973	52 955	355 527
Fibre clay Äänekoski	0	3 939	199 150	45 364	248 453

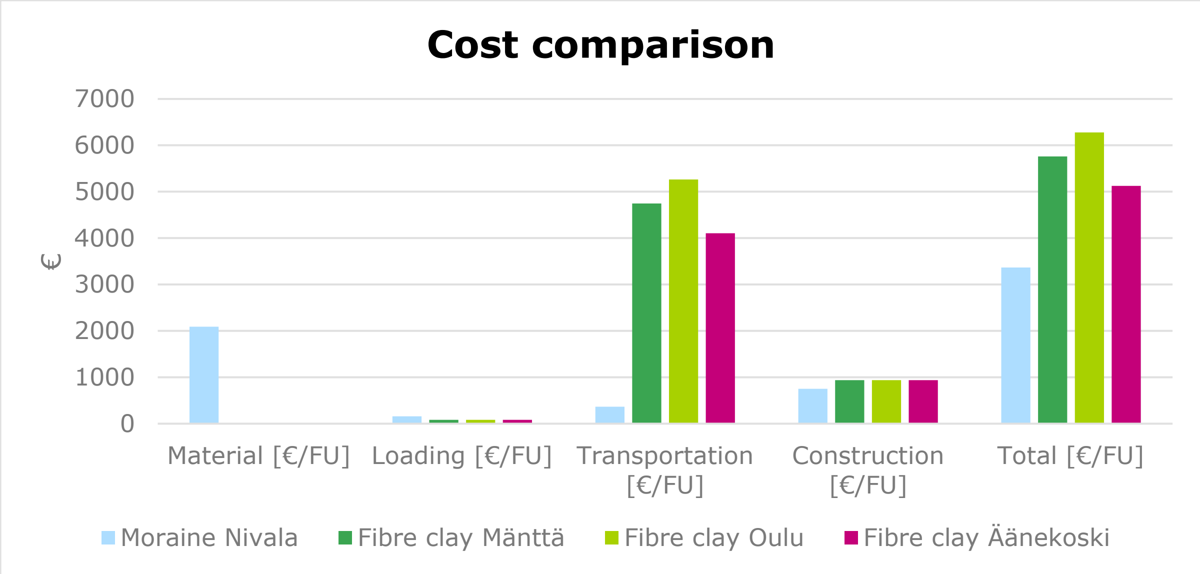


Figure 6. Fibre clay structures costs comparison by functional unit 1000 m^2.

Summary

In general fibre clay is about 1,5 times more expensive material to be used, which were result from long transportation distances. Fibre clay from Äänekoski seems to be cheapest of clays which is logical because it is not as dense as fibre clay from Oulu. If the transportation costs of fibre clays are ignored, the material itself is cheaper than moraine. The fibre clays can be considered as better material because they are more consistent and have more homogenous structure. The quality of the moraine varies more than clays. Therefore, it can be expected that their performance as cover structure is also better than moraine and the probability of failures is smaller. However, the fibre clay is partly biodegradable which need to take account to maintain layer thickness after some time, but degradation clogs the layer and water permeability decrease.

4.2 Alternative cover structure case

In this alternative case, fibre clay production distance is imaginary (50 km from Hitura site). The moraine transportation distance (37 km) is as well a bit longer than previously. The 37 km is distance from Ylivieska quarry to Hitura using main roads. The route is shown in the figure 7. This case will show better positive impacts when construct with utilizing by-products. The construction stages and vehicles used in the construction process are similar for those previously describe (Table 8).

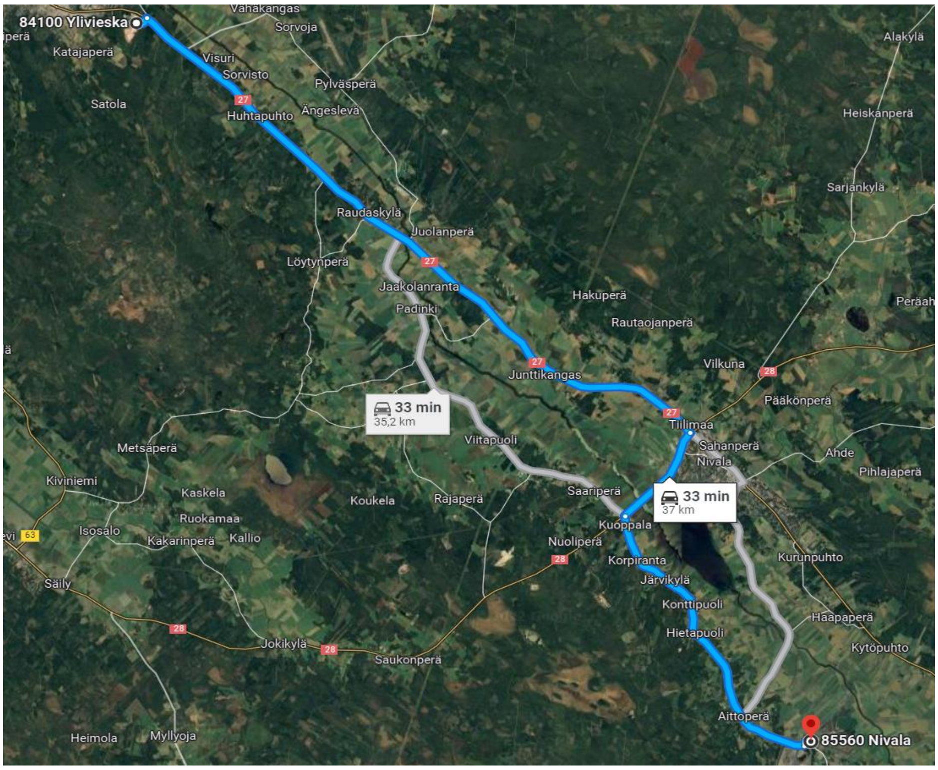


Figure 7. The route from Ylivieska quarry to Hitura using main roads.

Structures, loading and transportation methods are as previously. Only varying parameter is transportation distances which are in Table 16.

Table 16. Distance and driven kilometers per FU.

	Material	Distance to Hitura mine [km]	Driven kilometers/FU [km]
Option 1	Moraine	37	383
Option 2	Fibre clay	50	362
Option 3	Fibre clay	50	473
Option 4	Fibre clay	50	369

Results

Table 17. Results of the GHG emission per FU of alternative fibre clay cover structure piloting in Hitura mine.

	Materials [kg CO_2 eq]	**Transportation** [kg CO_2 eq]	**Construction** [kg CO_2 eq]	**Total emissions** [kg CO_2 eq]
Nivala	375	766	293	1 435
Mänttä	32	724	362	1 118
Oulu	32	948	362	1 342
Äänekoski	32	739	362	1 134

Table 18. Results of the energy consumption per FU of fibre clay cover structure piloting in Hitura mine.

	Materials [MJ]	**Transportation** [MJ]	**Construction** [MJ]	**Total energy consumption** [MJ]	**Total consumption per tonne of material** [MJ/tonne]
Option 1 Moraine	2 514	11 571	3 951	18 037	43,57
Option 2 Fibre clay (Mänttä)	1 310	10 925	4 884	17 119	59,18
Option 3 Fibre clay (Oulu)	1 310	14 305	4 884	20 499	54,12
Option 4 Fibre clay (Äänekoski)	1 310	11 161	4 884	17 355	58,73

Table 19. Results of the depletion of natural resources per FU of fibre clay cover structure piloting in Hitura mine.

	Materials [kg]	**Transportation** [kg]	**Construction** [kg]	**Total consumption** [kg]	**Total consumption per tonne** [kg/tonne]
Option 1 Moraine	414 026	370	127	414 524	1001
Option 2 Fibre clay (Mänttä)	14	50	157	521	1,80
Option 3 Fibre clay (Oulu)	14	458	157	629	1,66
Option 4 Fibre clay (Äänekoski)	14	357	157	528	1,79

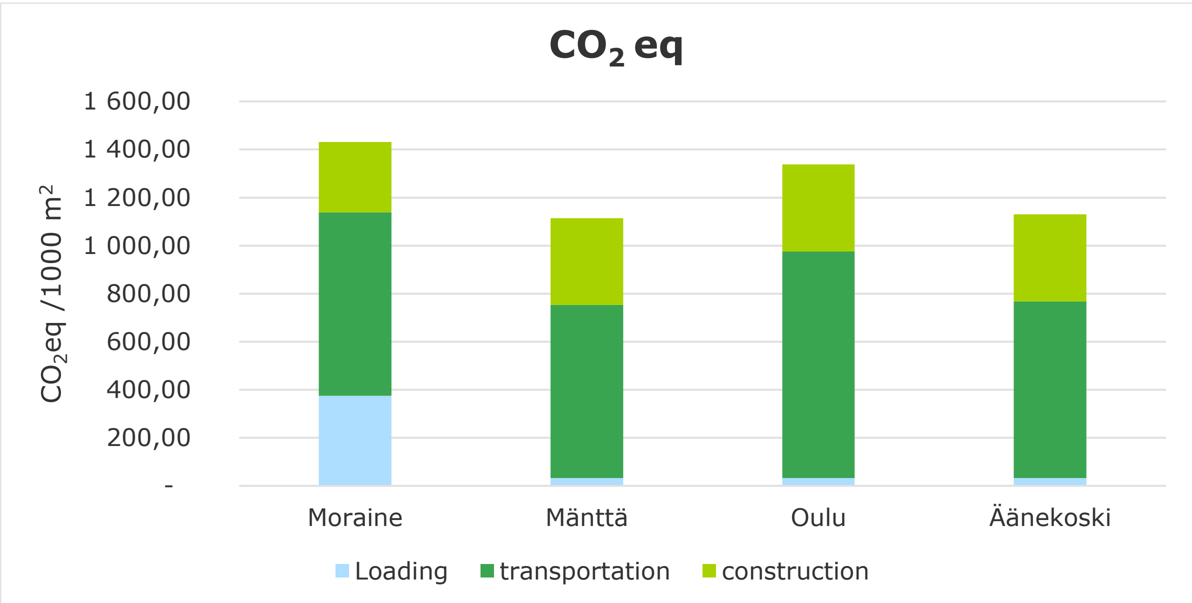


Figure 8. Results of the GHG emission per FU of fibre clay and moraine cover structure scenarios in Hitura mine.

In this case using fibre clay constructions have almost same environmental effects caused by CO_2 eq emissions as moraine (figure 8). Fibre clay is less dense than moraine which cut transportations environmental impact. Moraine layer is also 50 mm thinner than fibre clay layers but still produces more CO_2 eq emission. When comparing more closely, using moraine causes mush higher depletion of natural resources. When the distance is almost same than moraine, fibre clay utilization is more environment friendly solution.

4.3 Alternative case LCC

Work and structures are same than in original case, but in this alternative case every fibre clay producer is at the distance of 50 km from construction site and moraine is transported from quarry which located 37 km a way. Fibre clays transportation cost are estimated directly by dividing previous case's cost to match shorter transportation distance. Example Mänttä's fibre clays transportation is calculated as 16,4 €/t x 50 km/282 km = 2,91 €/t.

Table 20. Transportation costs.

	€/km	€/tonne
Moraine	2,2	
Fiber clay Mänttä		2,91
Fiber clay Oulu		4,91
Fiber clay Äänekoski		4,66

Table 21. Cost dividing during construction per FU.

	Material [€/FU]	**Loading** [€/FU]	**Transportation** [€/FU]	**Construction** [€/FU]	**Total** [€/FU]
Moraine Nivala	2091	156	842	754	3843
Fibre clay Mänttä	0	81	841	936	1858
Fibre clay Oulu	0	81	1860	936	2877
Fibre clay Äänekoski	0	81	1377	936	2394

Table 22. Total cost dividing during construction.

	Material [€]	**Loading** [€]	**Transportation** [€]	**Construction** [€]	**Total** [€]
Moraine Nivala	243 027	18 134	97 933	87 661	446 755
Fibre clay Mänttä	0	3 556	36 811	40 949	81 315
Fibre clay Oulu	0	4 599	105 259	52 955	162 813
Fibre clay Äänekoski	0	3 939	66 752	45 364	116 055

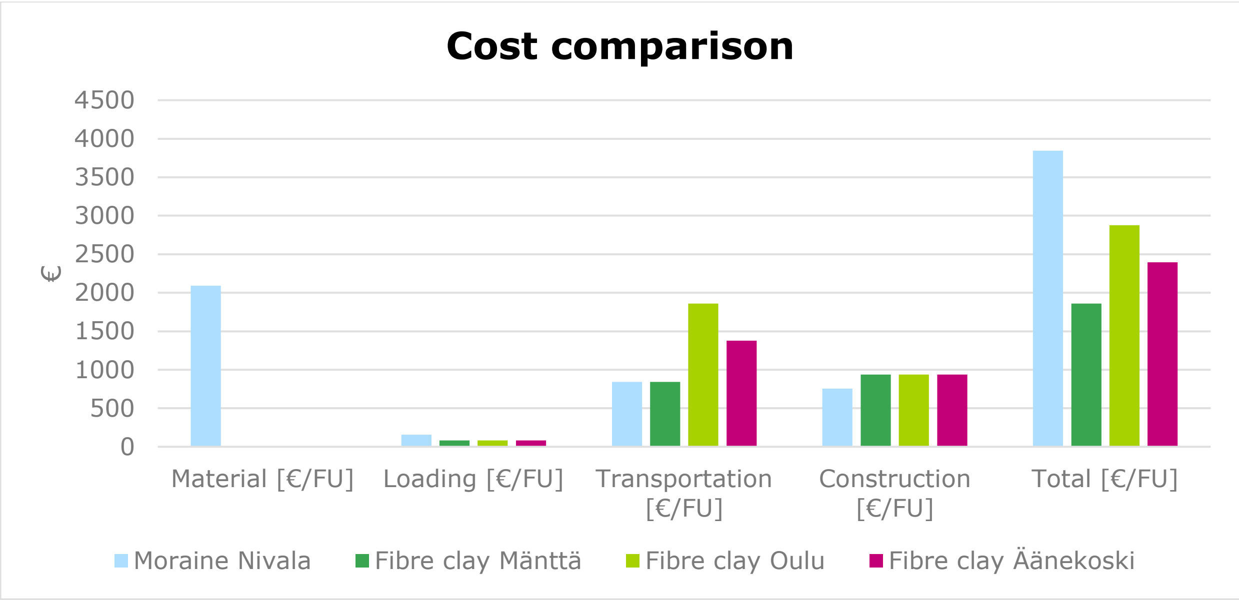


Figure 8. alternative cases fibre clay pilot structures costs comparison by functional unit 1000 m².

As can see from comparison of figure 6 and 8, the long transportation distance of fibre clays affect the most in life cycle cost analysis but if construction site would be closer then fibre clays are more cost-effective materials than moraine This LCC comparison indicate that fibre clay is cost effective solution for cover structures when site is nearer the producer. when taken account that fibre clay has much better water permeability properties than common moraines it is even more viable option when it can be utilized closer the source.

5. VERTICAL SEALING BARRIER PILOTING IN KUOPIO

The vertical sealing barrier piloting in Kuopio Sorsasalo's waste center is still ongoing and it is estimated to be finished at end of year 2022. For simplify the calculations it is assumed from this point on that structure is already finished. The vertical sealing barrier was about 2000 m^2 tight wall, which surrounded by drainage and backing layers. Thickness of the compacted clay layer was 1000 mm, and its purpose is to stop water end up from dangerous waste area to normal waste area. On both side of that is 500mm thick dranage layers which purpose is to prevent water standing against the clay wall. On both side is supporting layer which thickness is 5 m. Layers are shown in figure 9.

Figure 9. Vertical sealing barrier.

Reference structure is the conventional alternative when the sealing structure is made of virgin materials. The FU unit is 1 wall m^2 from horizontal viewpoint perpendicular to wall. Whole structure is total 2000 FU units.

Table 23. Alternative cover structures compared in the LCIA.

Structure	Description
Structure	Surplus and waste materials
Reference structure	Virgin materials (moraine, gravel, sand, crush)

The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***.

Material production

Materials which are used in sealing structure in Kuopio were waste or surplus materials. Materials production doesn't produce emissions. Moraine, gravel and sand are virgin materials and therefore the emissions from the production have been taken into account in the LCIA. NCC quarry from Mäntsälä [12] is used as reference when calculating virgin materials impact to LCIA.

Table 24. Materials.

Original structure	Description	Volume (m^3)
Compact layer	Surplus clay from Mäkelä and Hamula	2000
Drainage layer	Ash from Riikinvoima Oy	1950
Supporting backfill	Surplus soils, Hitura's sediment from water treatment and ash from Mondi Powerflute Oy	24 000
Alternative structure	**Description (NCC product)**	**Volume (m^3)**
Barrier layer	Moraine (Rock Fines 0/3)	2000
Drainage layer	Gravel (Coarse rock 6/32)	1950
Supporting backfill	Gravel and sand (All-In Rock 0/150)	24 000

Transportation

Table 25. Transportation.

Material (Original structure)	Volume [t]	Distance [km]	CO_2 eq [kg]	CO_2 eq [kg /wall m^2]
Surplus clay (Mäkelä)	450	270	6457	3,2
Surplus clay (Hamula)	2 550	22	2795	1,4
Ash from Riikinvoima Oy	2 535	82	10 357	5,2
Sediment from Hitura's water treatment	3 600	206	36 951	18,5
Ash from Mondi Powerflute Oy	2 250	1	112	0,06
Waste materials from waste center	28 500	0,3	992	0,5
Material (alternative structure)	**Volume** [t]	**Distance** [km]	**CO_2 eq** [kg]	**CO_2 eq** [kg/wall m^2]
Moraine, barrier layer	3 000	21	3 139	1,6
Crush, drainage layer	2 925	21	3 061	1,5
Sand and gravel, support layer	35 250	21	36 883	18,4

Waste material such as surplus soil is estimated to be transported approximately 300 m distance.

Construction

The construction stages and vehicles used in the construction process are similar for all alternative structures (Table 26). At the first construct compact layer with an excavator. After that, the compact layer support with other layers. Backing layer is compacted with a dumper. Working methods and working hours are same in both constructions.

Construction work is calculated by using information from constructor who estimated that working speed were 3 m^2/h. When wall's area is about 2000 m^2 that make total work time 667 h. Constructor said also that they used 1 dumper and 2 excavators which were 30 tonne and 22 tonne. Dumper was used as compactor as it drove multiple time over supporting layers during transportation. Due to that there was no need for additional compacting. The dumper was estimated to be like normal earth moving vehicle factor wise and bigger excavator power usage were estimated to be 130 kW but other factors as average excavator in Lipasto's databank [2].

Table 26. Construction vehicles and their GHG emissions.

Stage	**Working machine**	**Working hours**	**CO_2 emission** [kg]	**CO_2 emission** [kg / wall m^2]
Spreading of the material	Excavator 30T	667	21 791	10,9
Spreading of the material	Excavator 22T	667	17 633	8,8
Compacting & transportation	Dumper	667	25 287	12,6

Results

The climate impacts of the sealing structure piloting alternatives are presented in Table 27.

Table 27. Results of the GHG emission of the sealing structure piloting in Kuopio.

Structure	**Materials** [kg CO_2 eq]	**Transportation** [kg CO_2 eq]	**Construction** [kg CO_2 eq]	**Total emissions** [kg CO_2 eq]	**Total emissions per wall m^2** [kg CO_2 eq/m^2]
Original structure	975	57 971	64 712	123 604	61,8
Alternative structure	114 788	43 083	64 712	222 582	111,3

Energy consumption is estimated from calculated power usage using **Lipasto databank's values**. This approach is selected because there is not real fuel consumption data from transportation and construction. Materials production energy consumption is not calculated for original structure because values for crushing and screening are not available. For alternative structure is used Mäntsälä quarry information [12]. Energy consumption of the sealing barrier material alternatives are presented in Table 28.

Table 28. Results of the energy consumption sealing structure piloting in Kuopio.

Structure	**Materials** [MJ]	**Transportation** [MJ]	**Construction** [MJ]	**Total energy consumption** [MJ]	**Total consumption per wall m^2** [MJ/m^2]
Original structure	-	868 125	874 082	1 742 207	871
Alternative structure	1 507 050	653 176	874 082	3 034 308	1517

Depletion of natural resources is calculated from power consumption. There is also taken account moraine, gravel and sand consumption which leads much bigger consumption of nonrenewable materials. Results are presented in Table 29.

Table 29. Results of the depletion of natural resources in sealing structure piloting in Kuopio.

Structure	**Materials** [kg]	**Transportation** [kg]	**Construction** [kg]	**Total consumption** [kg]	**Total consumption per wall m^2** [kg/m^2]
Original structure	0	27 780	32 065	59845	9,9
Alternative structure	89401	20 902	32 065	142 367	71,2

Summary

Kuopio's sealing structure environmental effects are clearly smaller in original constructed structure than alternative structure by using only virgin materials. By using virgin materials the construction GHG-emissions are bigger and depletion of natural resources grows clearly. The energy consumption is bigger in original structure than alternative structure because Hitura's water treatment sediment was transported for a long distance. Most important thing to notice is that distance affects alternative materials CO_2 emission.

The figure 10 shows scenario where the original structure is made without water treatment sludge transportation cost, when the emission of the structure is almost half compared to the virgin material's structure. The sludge from Hitura is transported to Sorsasalo anyway so transportations emissions is not caused directly by construction of vertical sealing barrier.

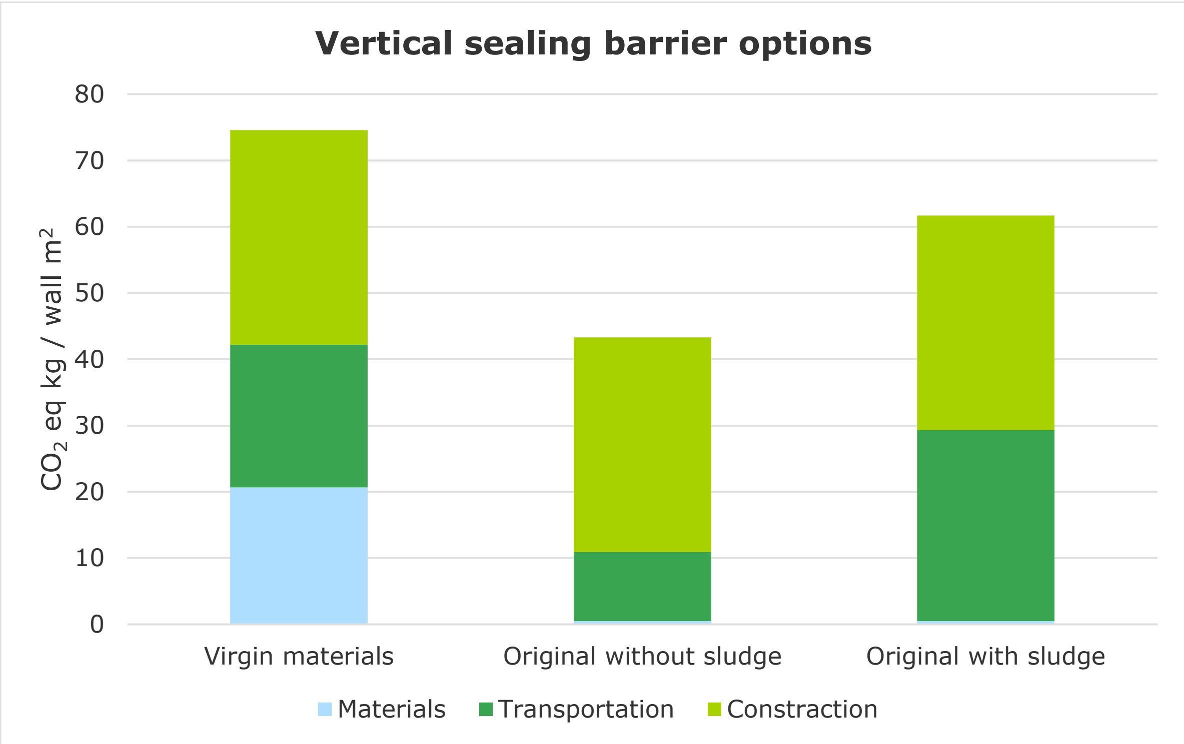


Figure 10. Results of GHG emissions of the sealing structure options.

Virgin materials has assumed to be produced in single quarry and from virgin soil that needed to be crushed. The data can vary between quarry's and that may create some over or under estimations. This comparison gives at least direction of how big impact would be if virgin soils would be used.

5.1 LCC of vertical sealing barrier

Functional unit for LCC is 1 m^2 of wall. The compared structures are original, original without Hitura's wastewater treatment sludge transportation and structure with virgin material.

Table 30. Work costs of used machinery.

Working machine	**€/h**
Doosan 21,5 tonne (excavator)	75

Doosan 30 tonne (excavator)	85
Dumper	95

All materials transportation cost is calculated using constant value 2,2 €/km. Surplus and secondary materials are free in original case and only compared alternative structures materials need to bought prices has estimated from billings.

Table 31. Material purchasing costs.

Material	**Price** [€/tonne]
Moraine (sealing layer)	5,05
Gravel (drainage layer)	13,25
Sand (support layer)	9

Total cost of structures is calculated first and then it is divided by area of structure which is 2000 m^2 to get cost per functional unit 1 m^2. Total cost is in Table 33 and cost per functional unit is in table 32.

Table 32. Cost dividing during construction per wall m^2.

	Material [€/m²]	**Transportation** [€/m²]	**Construction** [€/m²]	**Total** [€/m²]
Original structure	0	32	85	117
Original (without transportation of sludge from Hitura)	0	11	85	96
Alternative structure	186	24	85	294

Table 33. Total cost dividing during construction.

	Material [€]	**Transportation** [€]	**Construction** [€]	**Total** [€]
Original structure	0	63 548	170 000	233 548
Original (without transportation of sludge from Hitura)	0	22 958	170 000	192 958
Alternative structure	371 156	47 557	170 000	588 713

In figure 11 is compared all structures total prices and each cases material, loading, transportation and construction costs.

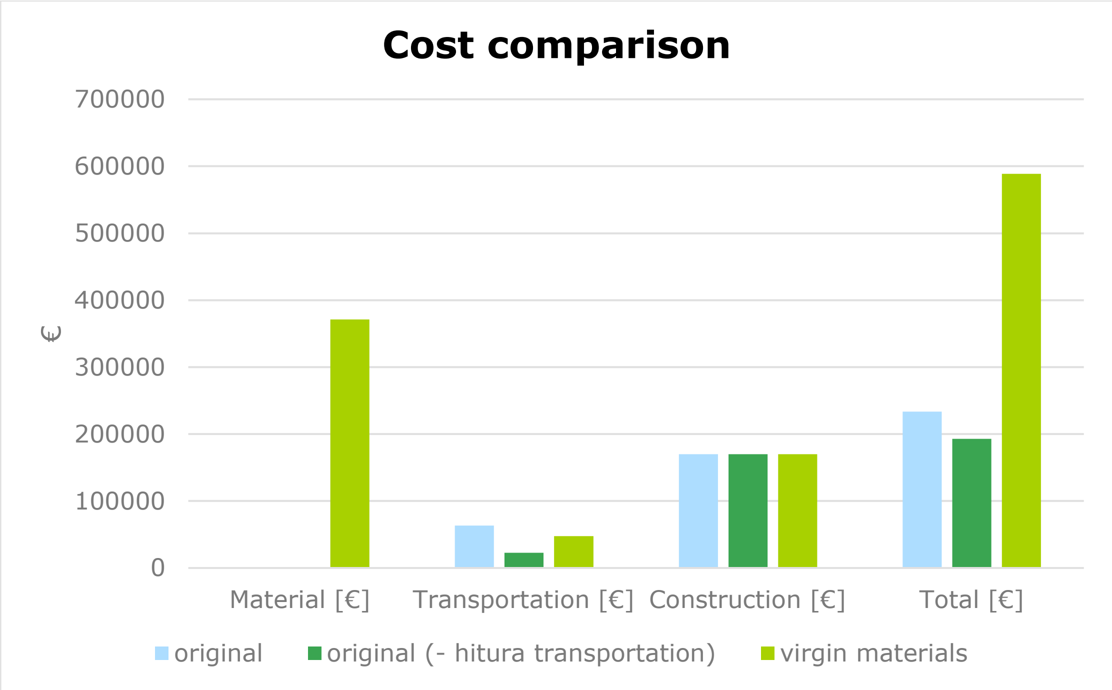


Figure 11. Vertical sealing barrier pilot structures costs comparison by total prices.

As can see from figure 10 the original structures cost is about 2/5 - 1/3 from alternative virgin material structure. It conforms about main idea of UPACMIC and resource efficiency idea, that if construction sites own material can be utilized it is most cost efficient and environmental solution. It can be discussed does Hitura's wastewater treatment sludges transportation cost belong to construction costs, while it is anyway transported to Sorsasalo's landfill area.

6. SURPLUS CLAY COVER STUCTURE IN HITURA

The surplus clay cover structure piloting in Hitura mine was about the size of 3,3-hectare area. The thickness of the clay layer was 500 mm. Structure is shown in figure 6. Reference structure is the conventional alternative, when the cover structure is made of moraine originated from Nivala or nearest fibre clay originated from Oulu.

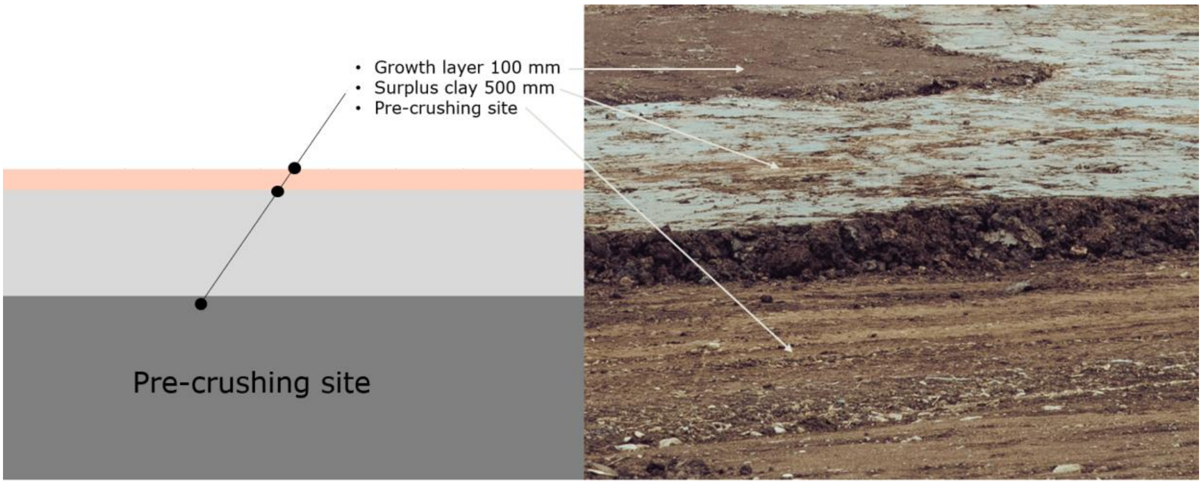


Figure 12. Pre-crushing site cover structure.

Table 34. Alternative cover structures compared in the LCIA.

Alternative structure	Description
Structure	surplus clay, origin from Hitura
Reference structure	moraine, origin from Nivala
Fibre clay structure	fibre clay, origin from Oulu

The functional unit (FU) of the LCIA is 1000 m^2 of the cover structure. Soil (growth layer) is not included in the assessment because it is equal in all cover structures in this project. Laboratory works is not included because the suitability of the materials must be verified for each construction material. The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***.

Material production

Surplus clay and moraine which was used in structures alternative are virgin materials and therefore the emissions from the production have been taken into account in the LCIA. Since the clay used in the construction of the cover structure were not processed, the aspects of materials production are mainly related to its excavation. The differences in environmental effects consist of transport distances and equipment.

Table 35. The materials used in the different structure alternatives.

Material	Thickness [mm]	Area [m^2]	Volume [m^3]	Volume/FU [m^3]
Surplus clay	500	33 941	17 000	500
Moraine	500	33 941	17 000	500
Fibre clay	500	33 941	17 000	500

Transportation

Surplus clay is transported using tractor and ERT Granger 18T JLV cart. With on drive tractor can transport 18 tonne clay. Cassette truck is estimated to be able to transport 40 tonne moraine at a time.

Table 36. The materials transport distances and total distance for FU.

	Transporting vehicle	Distance to Hitura mine [km]	Driven kilometers/FU [km]
Surplus clay	Tractor and trailer	0,3	35
Moraine	Cassette trucks	16	414
Fibre clay	Cassette trucks	167	3 163

Construction

The thickness of the original piloted cover structure (surplus clay) is 500 mm. The construction stages and vehicles used in the construction process are similar for all alternative structures (Table 37). The construction of the cover structure starts with spreading the material (moraine / fibre clay) with a bulldozer. After spreading, the compacting is done with a skid steer excavator. The compacting is done by driving over the material three times. Stocks of the excavator is 800 mm width and compacting work is calculated by excavator driven kilometers.

Table 37. Construction vehicles and their working hours per FU.

Stage	Working machine	Working hours / FU
Spreading of the material	Bulldozer	11
Spreading of the material	Excavators, skid steer	11
Compacting	Excavators, skid steer	0,4

Results

The climate impacts of all cover structures options is presented in Table 38.

Table 38. Results of the GHG emissions per FU of all cover structure options.

Structure	Materials [kg CO_2 eq]	Transportation [kg CO_2 eq]	Construction [kg CO_2 eq]	Total emissions [kg CO_2 eq]	Total emissions per tonne of material [kg CO_2 eq/tonne]
Surplus clay	158,7	70	707	937	0,91
Moraine	153,5	828	707	2475	1,63
Fibre clay	64,0	6331	707	7103	9,38

Energy consumption of all cover structures options is presented in Table 39.

Table 39. Results of the energy consumption per FU in all cover structure options.

Structure	Materials [MJ]	Transportation [MJ]	Construction [MJ]	Total energy consumption [MJ]	Total consumption per tonne of material [MJ/tonne]
Surplus clay	693	929,3	9551	22 753	21,98
Moraine	660	12509	9551	11 140	10,76
Fibre clay	289	95560	9551	105 399	139,14

Depletion of natural resources of all cover structures options is presented in Table 40.

Table 40. Results of the depletion of natural resources per FU in all cover structure options.

Structure	Materials [kg]	Transportation [kg]	Construction [kg]	Total consumption [kg]	Total consumption per tonne of material [kg/tonne]
Surplus clay	69	30	307	403	0,39
Moraine	1 035 067	400	307	1035774	1001
Fibre clay	28	3058	307	3939	4,5

Summary

Distance is the most effective factor between materials when comparing CO_2 emissions (figure 11). Materials production emissions consists of loading, and construction work is same with all materials. When taking account moraine effect to depletion of natural resources is other materials clearly much sustainable solutions.

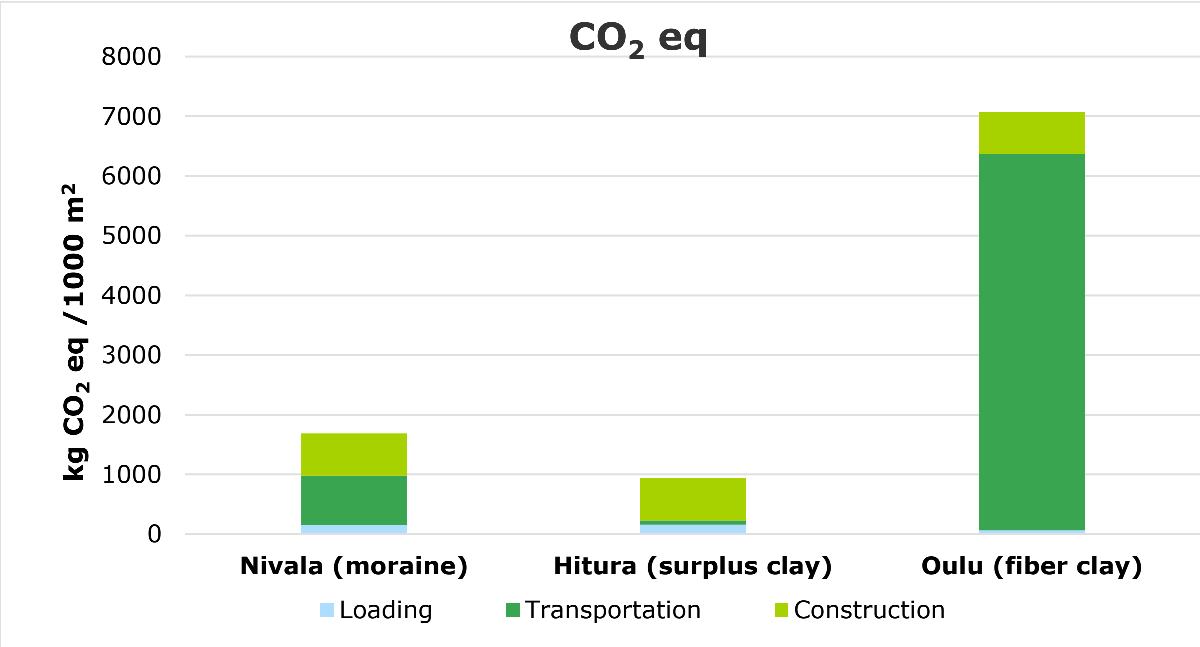


Figure 11. Results of the GHG emissions in all cover structure options.

6.1 LCC of Hitura surplus soil cover structure

Surplus soil was excavated mostly from nearby field. that excavation work needs also measure man with excavator which makes excavation cost higher. Construction's excavator work prices are higher because executive contractor is different than fibre clay covers.

Table 41. Work costs of used machinery.

Working machine	**€/h**
Wheel loader	65
Bulldozer	90
Excavator, skid steer (surplus soil excavation)	125
Excavator, skid steer	94,5

Moraine and surplus soil are bought from contractors and local farmers. The fibre clay is free.

Table 42. Material purchasing cost.

Material	**Price** [€/tonne]
Moraine	5,05
Surplus soil	1,29
Fibre clay	0

Surplus soil is transported by tractor and that transportation cost is calculated using time that took to transport material to construction site. Transportation is done by tractor.

Table 43. Transportation costs.

	€/h	**€/km**	**€/tonne**
Moraine		2,2	
Surplus soil	55		
Fibre clay			13,9

Costs are calculated using four sector which are materials, loading, transportation and construction. Total cost is sum of those.

Table 44. Cost dividing during construction per FU.

	Material [€/FU]	**Loading** [€/FU]	**Transportation** [€/FU]	**Construction** [€/FU]	**Total** [€/FU]
Moraine	5227	390	911	2065	8592
Surplus soil	1335	750	190	2065	4340
Fibre clay	0	163	10529	2065	12757

Total cost of structures is calculated by multiplying by amount of FU units in full structure.

Table 45. Total cost dividing during construction.

	Material [€]	**Loading** [€]	**Transportation** [€]	**Construction** [€]	**Total** [€]
Moraine	177 401	13 237	30 913	70 086	291 638
Surplus soil	45 316	25 456	6 440	70 086	147 298
Fibre clay	0	5 515	357 373	70 086	432 975

In figure 12 is compared all structures total prices and each cases material, loading, transportation and construction costs.

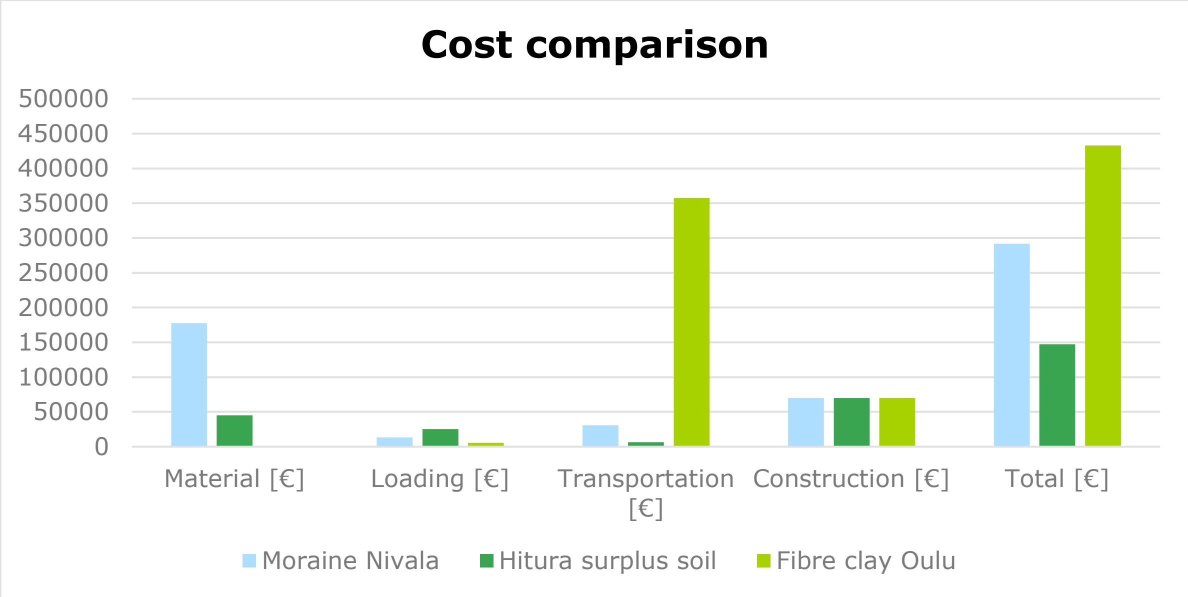


Figure 12. Pre crushing sites cover structure total costs comparison.

All figure's 12 case structures are same size so these can be compared directly by total cost. As can see original surplus structure is most cost-effective solution. Fibre clay from Oulu is most in attractive compared to other material solutions. If the site would be closer, the chart would looks different.

7. CONCLUSION

Surplus soils and materials seem viable option when considered costs and impacts on environment, but material sources need to be close to achieve the best results. UPACMIC (Utilisation of by-products and alternative construction materials in new mine Construction, LIFE12 ENV/FI/000592) project's pilots in Hitura were far from material producers which affect a lot to results of LCIA and LCC comparison. The UPACMIC project's goal was to demonstrate possibilities and viability of industrial by-products and surplus soils in mine environment and encourage utilizing new materials in exchange for natural resources. That was considered to be more important than fibre clay piloting carbon emission.

The fibre clay is partly biodegradable which needs to be taken into account to maintain layer thickness after some time, but degradation clogs the layer which makes it even less permeable, so its properties improve over time. Maintaining layer thickness was the reason behind different thicknesses of pilot structures (200 vs 250 mm). Another benefit of using fibre clay is that it doesn't crack when it dries as natural moraine does. That makes fibre clay sealing layer more durable against weather actions.

The transport distance affects the most to fibre clay utilization in emission and cost when compared direct cost and emissions. However, in the comparison undirect impacts were leaved out due to complexity. When material would be disposed as waste and not been utilized, indirect impacts would be for example landfill area establishing, maintenance and eventually closing. That would generate emission, energy usage, depletion of natural resources and costs. In Finland there is also waste tax which can be avoided when waste can be utilized as material. Rough estimation of total price of one tonne waste disposal is at least about 100 €. If indirect costs were taken in account, the cost comparison would look different. If this project encourages in the future fibre clay utilization closer of the source it would eventually overturn the emissions of these pilots.

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