Final report

1.1 Project details

Project title	New cover solution for the pit heat storage in Marstal
Project identification (program abbrev. and file)	EUDP-2008. EUDP File no. 63011-0089
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	PlanEnergi Jyllandsgade 1, 9520 Skørping
Project partners	Steinbeis forschungs- und entwicklungszentrum Gmbh Rambøll Marstal Fjernvarme GG-Construction
CVR (central business register)	74038212
Date for submission	January 2015

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1.2 Short description of project objective and results

The aim of the project was to design and demonstrate a new floating cover solution for an existing 10,000 m^3 pit heat energy storage in Marstal.

The expected result was that the floating cover solution was designed and demonstrated, and that the total design could be replicated in coming water storage solutions more than 50,000 $m^{3.}$

The result has been design of four different solutions, but none of them is demonstrated because Marstal Fjernvarme found corrosion in the pipes and other metal parts of the pit heat storage and therefore found it too expensive to renovate the storage.

1.3 Executive summary

Marstal Fjernvarme implemented a 10,000 m^3 pit heat storage in 2004. A leakage in the manhole meant, that the cover insulation was wet and lost insulation capacity. Therefore and because the construction caused problems with air pockets under the lid and puddles of water on the roof foil, Marstal Fjernvarme got EUDP support to design and implement a new cover construction.

During the project four new cover solutions has been developed. The idea was, that the new cover solution should be tested at the 10,000 m^3 storage before implementation at a 75,000 m^3 full scale storage, but for different reasons this was not possible. In the beginning of 2014 Marstal Fjernvarme had a diver to investigate the 10,000 m^3 storage. The diver found corrosion on pipes and iron construction. That made Marstal Fjernvarme to give up the renovation project of the 10,000 m^3 storage because it would be too expensive and because they meant, that the capacity in their new built 75,000 m^3 pit heat storage will be enough in the future.

This final report therefore includes a description of the four cover solutions and the estimated prices for the solutions. The solutions and prices are:

Solution	Estimated price/m^2, full scale
LECA. Leca is placed on a cover liner. Top with Rockwoll and top membrane	96
STEEL. Special elements of PUR surrounded with aluminium is assembled and floating on the water	90
DC-System. Standard elements of PUR and covered with stainless steel on the water side is assembled and floating on the water	111
SPU. Standard elements of PUR is combined to a floating construction placed on a cover line	84

None of the constructions has been tested in pilot or full scale, but during the project corrosion was found in the pipes in the 75,000 m^3 storage in Marstal. To prevent further corrosion Ph has been raised to 9.8. That means the aluminium based solutions will be corroded and the aluminium in these constructions has to be changed to stainless steel. That might raise the price with app. 20 €/m^2. Thus the prices for the PUR solutions will be in the same level.

Taken that info account, the DC-System-Solution is most promising for further investigations. Also the LECA-solution can be interesting. But it has a couple of disadvantages: [1)] The cover is constructed for a fixed water level and [2)] if air condition in the LECA insulation does not function as expected, there will be a risk of diffusion of water vapour into the LECA insulation.

1.4 Project objectives

Marstal Fjernvarme implemented in 2004 a 10,000 m^3 pit heat storage as part of the project SUNSTORE 2. The objective of the SUNSTORE 2 project was to show that the pit heat storage in combination with 18,300 m^2 solar collectors and 2,000 m^3 steel tank could supply Marstal Fjernvarme with 30 % of the yearly production. The project was supported from the Danish Energy Agency and EU´s 5th Framework Programme.

In September 2005 (after one year of operation) a leakage was recognized in the storage lid. The leakage was in the manhole and caused that the insulation in the lid was filled with water. The insulation was Rockwoll and EPS. These materials are not water resistant and thus lost their insulation capacity. The leakage was caused by use of a wrong quality of PE (Polyethylen) as material in the manhole. The material should have been similar to the HDPE-liner used as side liner and bottom liner for the lid.

Marstal Fjernvarme still used the storage with the reduced insulation capacity in the following years, but problems with air pockets under the bottom liner of the lid and water puddles on the top liner of the lid made Marstal Fjernvarme in 2008 to apply for EUDP-support for development and test of a lid concept that could solve the following problems:
Formation of air pockets under the lid
Formation of larger puddles of water on roof foil near the edge
Fissure in the side of the manhole causing moisturizing of the insulation.

The result was expected to be a well-functioning pit heat storage, where the total design could be replicated in coming water storage solutions as for instance Dronninglund.

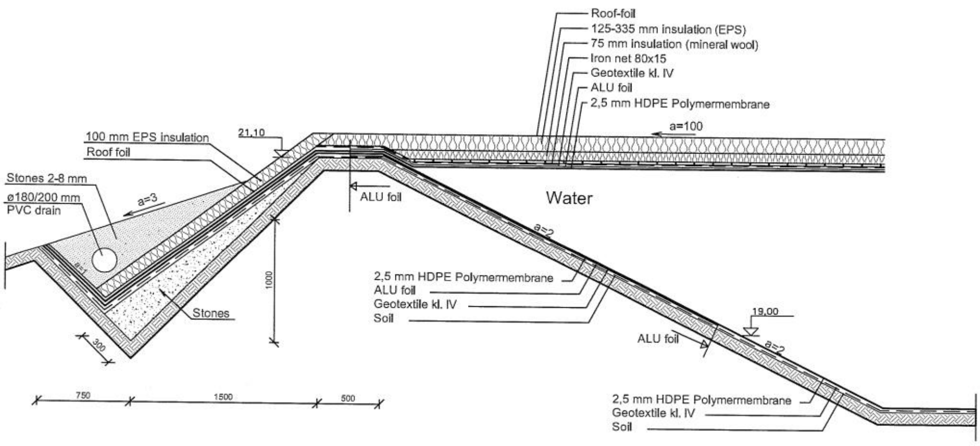

Figure 1: *Lock ditches and cover construction in SUNSTORE2 (Ref. 1)*

1.5 Project results and dissemination of results

The first meeting in the project group took place 02.11.2008 and the second meeting took place 10.11.2008. After those two meetings it was clear, that also the vapour barrier was not able to stand the temperatures. Hereafter the project group had designed a new cover solution with LECA as insulation material, but implementation of the solution could not take place because Marstal Fjernvarme had demanded compensation from Rambøll or GG-Construction for damages caused by the leakage in the manhole. GG-Construction did not accept to repair the cover before inspection and survey procedure was carried out in this case.

3rd Meeting in the project group took place 17.08.2010. In the meantime the LECA design had been detailed in the SUNSTORE 3 project in Dronninglund and Marstal Fjernvarme had got EU-support to the SUNSTORE 4 project, where implementation of a pit heat storage of 75,000 m^3 was included.

The idea was now to use the new cover construction as a pilot project before implementation of the cover in the SUNSTORE 4 project. Thus the call for tender for the pit heat storage in SUNSTORE 4 was based on the LECA-solution. The call for tender took place in the beginning of 2011. The price for the LECA-solution was as expected, but an alternative bid promised that a cover solution using PUR-elements was remarkably cheaper than the LECA-solution.

Marstal Fjernvarme decided to accept the alternative bid (later in the report called the STEEL-Solution), but the solution was not fully developed and tested. Therefore a project where the company, that should deliver this solution, should develop and test the PUR-elements was started in Spring 2011. Still the SUNSTORE 2 storage should be a pilot, where implementation experiences should be utilized in the SUNSTORE 4 storage.

During Summer 2011 test of the PUR-elements showed that they had to be protected against vapour diffusion with a metal liner because (against what the supplier had promised) it was not possible to find a polyurea coating that could resist vapour. To develop and test this solution took time. A final design from STEEL was ready in January 2012 and the SUNSTORE 4 cover should be implemented in Spring 2012. That meant that there was no time to implement a pilot solution before implementing the full scale solution. Also the price of the STEEL-Solution was now similar to the price of the LECA-solution.

The supplier of the liner, GSE, proposed in January 2012 an alternative cover solution with 240 mm foam insulation and with a price similar to the LECA and the STEEL Solutions. The board in Marstal Fjernvarme was nervous about implementing the STEEL solution in full scale, so they decided to accept the GSE-Solusion. The GSE-Solution is described in Ref. 2.

Marstal Fjernvarme still wanted to repair the SUNSTORE 2 storage and to test a new cover solution, but now the demand was a cheap solution because the SUNSTORE 4 project had been more expensive than expected. PlanEnergi therefore investigated the possibilities of using PUR standard elements and got prices from DC-System and SPU. The solution from DC-System was too expensive, but the solution from SPU met the price conditions set up by Marstal Fjernvarme. This solution was under development in Winter 2013-14. But in February 2014 a diver investigated the pipe construction in the SUNSTORE 2 storage and found it so corroded that it had to be repaired too. An estimate of these additional costs made Marstal Fjernvarme give up the project.

In this final report the above mentioned 4 cover solutions (LECA, Steel, DC-System and SPU) are descriped and prices are estimated for a cover to a 75,000 m^3 storage.

1.5.1 LECA-Solution
The LECA-solution was roughly designed in this project and detailed in the SUNSTORE 3 project in Dronninglund (Ref. 3). The design should solve the three problems mentioned in chapter 1.4 and problems with the vapour barrier.

Formation of air pockets under the lid.
Despite the use of automatic floatvents, practical use of the pilot storage demonstrates that air pockets are formed below the floating roof foil containing up to several m^3 of air. This happens because the water in the storage is not contained in a hermetically closed system, causing air to be released when the storage is charged at the relatively high temperatures for this process. This, of course, is negative for the production, since there is no possibility of removing these air pockets. For the LECA-solution storage more efficient air vents will be used (vacuum vents). For security reasons ventilation hoses will also be added in ten spots of the foil. These hoses will be made of HDPE material of the same temperature resistance as the liner and the feed through will be secured with double weldings. They will lead into ten inspection wells in which moisture in insulation can be surveyed and eventually pumped out and dried.

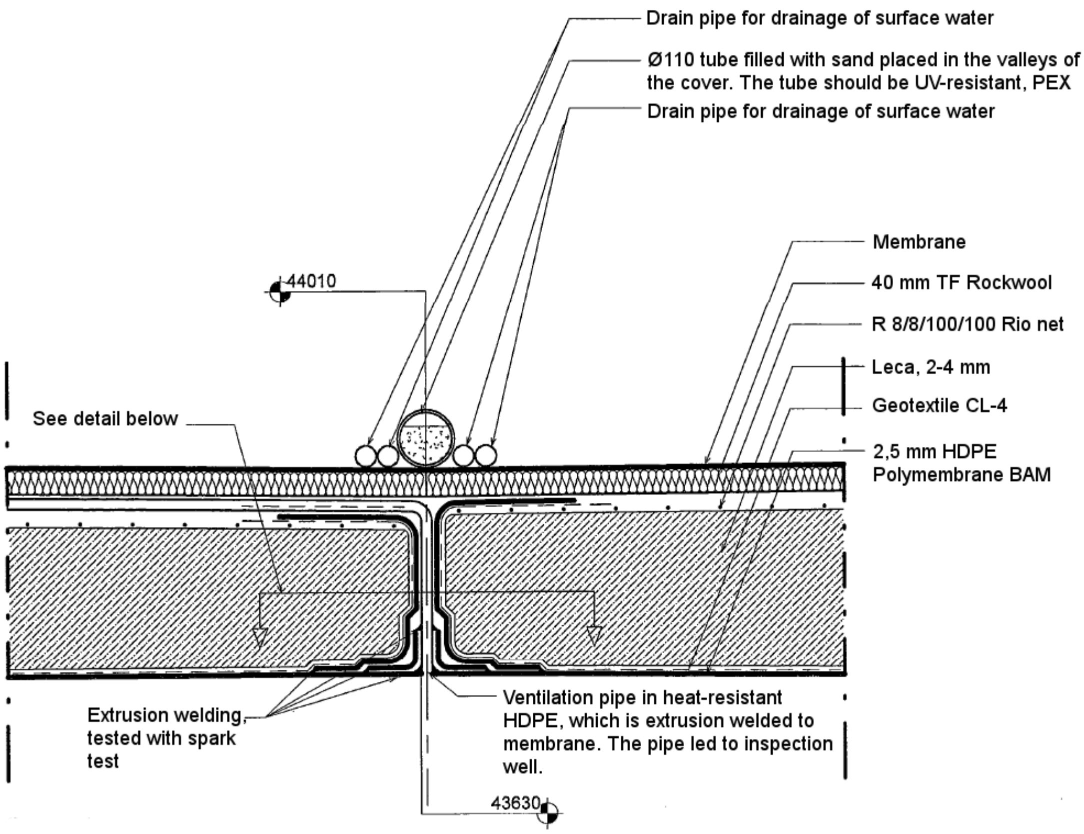

Figure 2: *Section of lid, bottom and ventilation. LECA-solution (Ref. 2)*

Formation of larger puddles of water on roof foil near the edge.
On the backgound of Marstal experiences, extra security will be established against the formation of puddles by the edge of the lid. This will be executed by constructing the lid with an extra slope of the edge zone as indicated below.

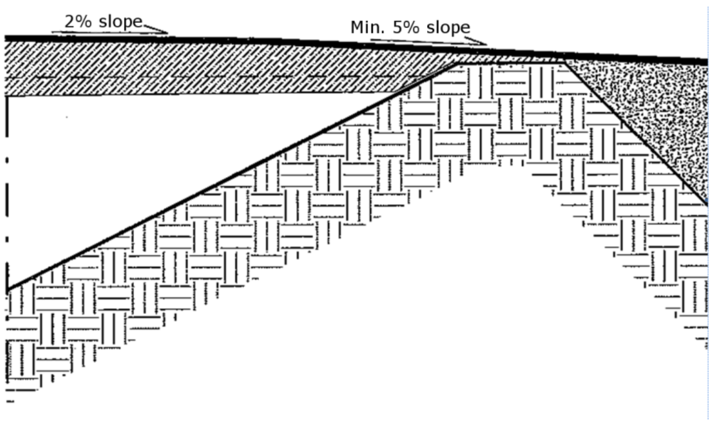

Figure 3: *Section near edge. LECA-solution (Ref. 2)*

Fissure in the side of the man hole, causing moisturizing of the insulation.
In the pilot storage the man hole was made using a strong corrugated sewer pipe of HDPE. This material, however, appeared not to possess the necessary properties concerning temperature resistance, causing a fissure to occur app. in the water surface. After a couple of years' use large amounts of water ran into the lid moisturizing the lower layer of mineral wool as well as part of the EPS insulation.

The hole itself was relatively easy to close by lifting the man hole free of the water using a pontoon but the ability to insulate the lid was significantly reduced and it was not possible to re-establish this with the insulation being dried.

Based on these experiences the man hole of the LECA-solution is equipped with a lining of the tested liner material shown in figure 4.

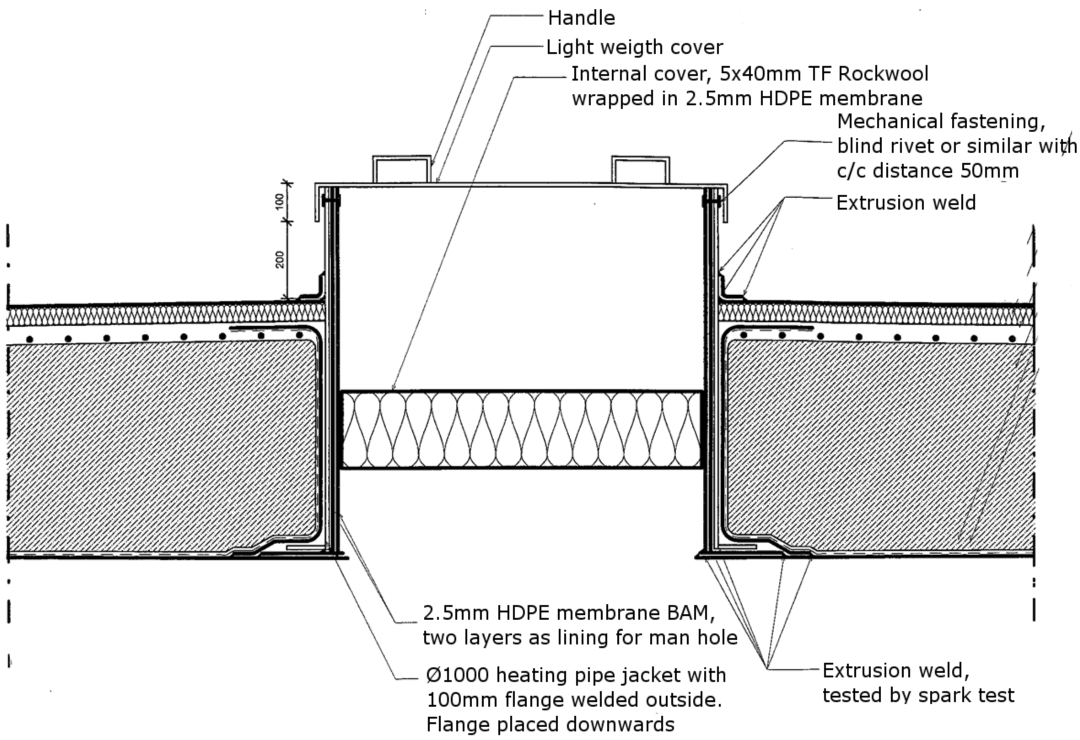

Figure 4: *Man hole. LECA-solution (Ref. 2)*

In order to avoid running into the same situation as the moisturization of the lid in the pilot storage, a different solution shall be used for insulation in the LECA-solution.

Other materials have been considered during the discussions. One example is mussel shells. Despite a higher lambda value (app. 0,12 W/mK) they would make the lid cheaper. However, that material was opted out because it will not be self sustaining in a situation where a leakage occurs in the lid. Perlite was opted out because of difficulties in handling. It is very lightweight and impossible to handle at the least wind - and it is difficult to make solid enough for treading on.

Expanded clay – here named by the Danish trade name, Leca – has been selected because it is temperature resistant, easy to put in place and can be transported in tubes by blowing. The supplier of Leca in DK is Weber.

Contrary to the floor constructions in which Leca is normally used, in this case, the highest temperatures are found in the bottom. Hence, there is a risk of convection.

This question has been discussed with our German partners in SOLITES. In this it discussion appeared that a Leca mixture of relatively small "balls" will be necessary. Based on Weber's own calculations, as shown below in table 1, the choice will be the '2-4' sorting as this is estimated to have a permeability of app. $2*10^{-8}$ m^2 and so a modified Raleigh number of app. 21. The norm of EN ISO 10456:2007 indicates 30 as the limit for convection in this type of insulation.

This conclusion has been put to the test in a practical test in cooperation between Weber and PlanEnergi. The test was carried out because permeability is very diffucult to decide at the very low air speeds relevant for convection flows. For this test, a model of app. 2 m^2 representing the lid insulation was tested using different sorting of Leca with and without separation layer to prevent convection. The test confirmed the theory, as it proved best to use either the 2-4 mm sorting without a separation layer or the 4-10 mm sorting with a separation layer. (The latter solution, however, was opted out since it is more difficult to handle and thus more expensive to establish).

Leca sorting		2-4	4-10	10-20
Total density	kg/m3	285	265	215
Nugget density	kg/m3	530	490	400
Porosity extern	%	46	46	46
Porosity intern	%	80	81	85
Lambda mean	W/mK	0,082	0,081	0,081
Lambda declared	W/mK	0,09	0,09	0,085
Permeability	m2	2,00E-08	4,00E-08	2,00E-07
With 65% RH :				
water in air	kg/m3	0,006	0,006	0,006
water in leca nugget	kg/m3	0,0912	0,0848	0,0645
water in leca nugget	%	0,032	0,032	0,03
water in insulation	kg/m3	0,091	0,085	0,067
water in insulation	%	0,032	0,032	0,031
Fm in ISO 10456		1,001	1,001	1,001
dT for insulation (average)	dg. C.	45	45	45
Ft in ISO 10456		1,15	1,15	1,15
Ft measured (dT 45 dg C.)		1,115	1,115	1,115
Corrected lambda value	**W/mK**	**0,104**	**0,104**	**0,098**
Convection:				
Air speed (estimate)	m/s	0,0005	0,0005	0,0005
thickness of insulation	m/s	0,52	0,52	0,49
dT for insulation (max.)	dg. C.	70	70	70
Rayleigh number		**21**	**42**	**210**

Table 1: *Data for Leca-sortings. LECA-solution (Ref. 2)*

As will be seen from table 1, corrections of lambda value owing to moisture content are insignificant, whereas corrections owing to the relatively high temperatures in the insulation are significant. In the following the value of 0,104 W/mK will be used for calculations as in table 1

Shown in figure 2 is the construction of the insulation. On top of the floating liner is a layer of geotextile to protect the liner mechanically. Then follows the Leca layer which is app. 375 mm thick in the section shown. On the top of this layer is a steel grid to make the Leca steady enough for treading on. Supporting the roof liner will be a hard mineral wool plate – here named by the Danish trade name, Rockwool (20 mm). The thickness of the Leca layer will vary in order to create the slope for rainwater to be conducted off the lid.

Water inside the lid: As shown in figure 5 the lid will be constructed in five lengthwise sections to allow the man holes and the inspection wells to be placed where the sections are thickest (app. 675 mm Leca) and the bottom of the lining is at its deepest. Any water inside the lid will collect there and thus be detected.
Air pockets: Ventilation holes and sectional borders will be placed in the four 'valleys' where the lid is thinnest and any air pockets under the lid will occur as shown in figure 2.

Rain water: The sandfilled pipe is positioned so as to weigh down the roof lining into the 'valleys' in situations where there is little wind, when the vacuum valves will not be able to secure the correct position of the lining in this place.
Through this construction a slope of app. 2% occurs on the top of the lid to conduct the rain water into the 'valley' and off the lid whereas an equivalent rise of app. 1% will be obtained on the inside of the lid to allow the air to run into the ventilation holes.

The heat loss in this construction may be read in table 2

a. at section border					b. at centre of section			
	lambda	thickness	resistance			lambda	thickness	resistance
	W/mK	m	m2K/W			W/mK	m	m2K/W
surface			0,04		surface			0,04
roof foil			0,02		roof foil			0,02
TF rockwool	0,039	0,02	0,51		TF rockwool	0,039	0,02	0,51
Leca 2-4	0,104	0,375	3,61		Leca 2-4	0,104	0,675	6,49
geotextile			0,10		geotextile			0,10
membrane			0,02		membrane			0,02
I alt			4,30		I alt			7,18
Heat loss	W/m2K		0,23					0,14
Average heat loss:			**0,19**	**W/m2K**				

Table 2: *Calculation of heat loss. LECA-solution (Ref. 2)*

Decomposition of vapour barrier.
No vapour barrier will be used in the bottom of the floating lid, partly because the advanced vapour barrier used in the pilot storage (3 layers of alu plus 2 layers of polyethylene) appear not to be able to resist the temperatures in the long run and partly because calculations have shown that it is possible through ventilation to get rid of the small amounts of water that diffuse through the liner.

Based on information about the vapour diffusion in the liners used, a calculation has been carried out for the similar storage in the Sunstore 3 project, concerning the amount of vapour steam that will diffuse through the floating liner as the effect of high temperatures. It amounts to app. 0,15 g/s (or app. 0,5 l/h) for the total surface. Assumed that the ventilation air temperature rises 10° C from intake to outlet it will be able to absorb app. 0,015 kg/m^3. This results in a ventilation need of 36 m^3/h for the complete lid.. This corresponds to a heat loss of app. 120 W. However, SOLITES has questioned this number, expressing that a rise in temperature of 30° C would be more likely. That will increase the loss to app. 500 W, but even this loss has no significance, as it will amount to only app. 2MWh during the summer.

Because of the small amount of air (it corresponds to a change of air of 1% per hour) the ventilation may be executed at a very low counter pressure – at app. 1 Pa.
In practice it is expected that the ventilation can be secured by means of the vacuum valves whose position may be as shown in figure 5 (Number and position has yet to be verified by supplier). Controlled air intakes may be introduced at the inspection wells in case they do not on their own provide sufficient change of air. If this is not sufficient either, then there must be established mechanical ventilation (suction) in connection with an inspection well in each section.

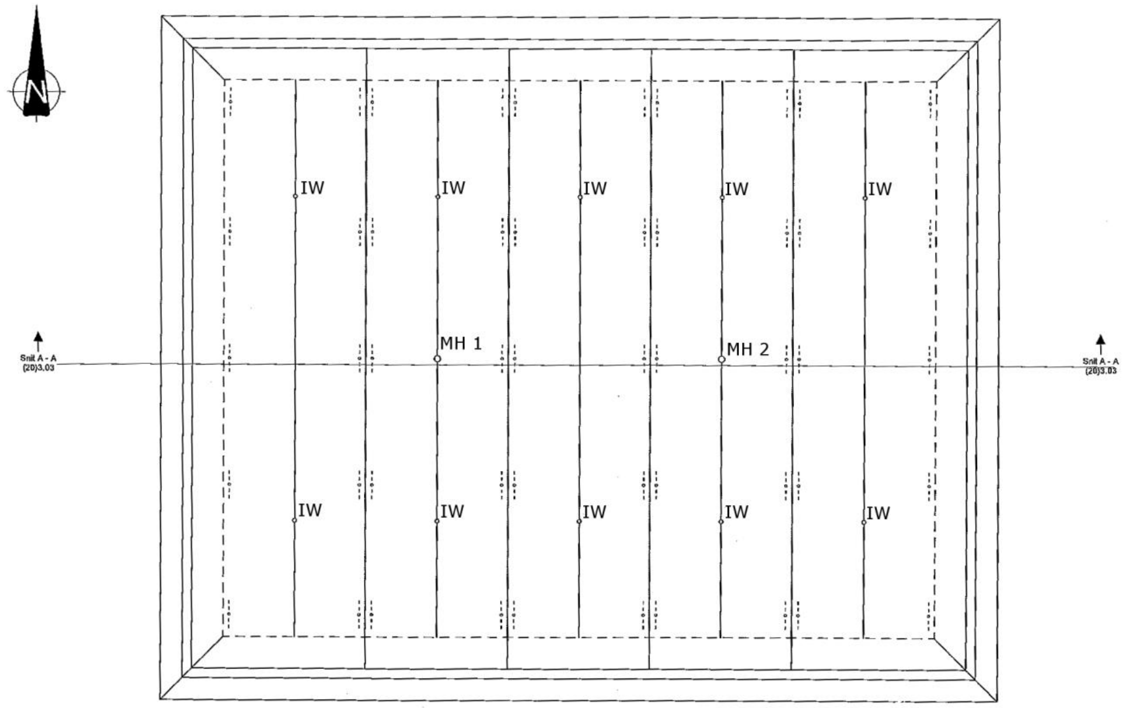

__Figure 5:__ Top view. MH=Manhole, IW=inspection well, --o-- = vacuum valve w. perforated tubes into the Leca layer. LECA-solution (Ref. 2)

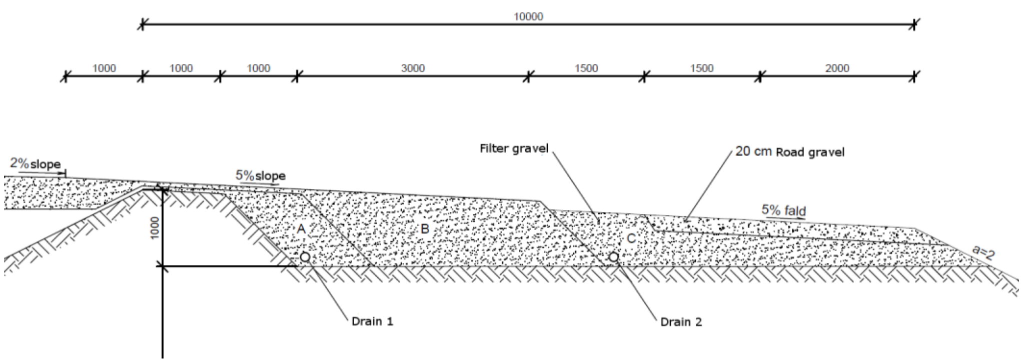

__Figure 6:__ Section of the edge with fastening dykes. LECA-solution (Ref.2)

The section design in the wall in figure 6 shows that the fastening of the membranes now have a different construction than in the pilot storage. Now it is possible to lock all three membranes one by one as the storage builds up. During the whole process and after it will be possible to drive around the storage on the wall. This will be necessary in connection with the build in of Leca for example, since that will happen with lorries with mounted blowing equipment. It must be possible to access from all sides with these cars, as they can only blow in a distance of up to 50 m.

The price for the LECA-solution is for the 75,000 m^3 storage in Marstal (88x 113 m).

Top membrane incl. implementation	421,500 €
LECA, geotextiles etc. incl. implementation	375,800 €
Cover liner incl. implementation	153,900 €
Total	951,200 €
Price/m^2	96 €

As can be seen the price for the top liner is high. Probably a cheaper solution can be found.

It is a disadvantage that the construction cannot follow the water level when the water in the storage is heated up and cooled down. Therefore water has to be added every year or a closed system with in- and outlet to an external water reservoir has to be implemented. Also there will be a risk of diffusion of water vapour into the LECA insulation if air conditioning does not work as expected.

1.5.2 STEEL-solution

The alternative lid design proposed by the company STEEL builds on the use of floating elements of PUR foam. The size and coating of these elements were not decided as tests had to be performed to prove the solution in respect to the following two potential problems, both caused by the high temperatures expected at the surface of the storage:
Form stability – eventual bending of the elements caused by the temperature difference between the floating surface (max. 90 dg. C) and the top (ambient temperature – min. 5 dg. C in the periods where the floating surface has very high temperatures).
Water vapour resistance. – Diffusion of water vapour into the PUR foam could lower the thermal resistance in the long term.

Form stability.
Because of limitations in the casting process a size of 2 by 6 meter was suggested in the bid. For an initial test four elements - each 1 by 4 by 0,2 meter - coated with polyurea were made. The coating was premade at glass fiber sheets. These premade coatings were placed in the form before casting.
The elements were glued together and placed in a test basin floating in 80° C water as shown in figure 7. Ambient temperature is app. 20° C.

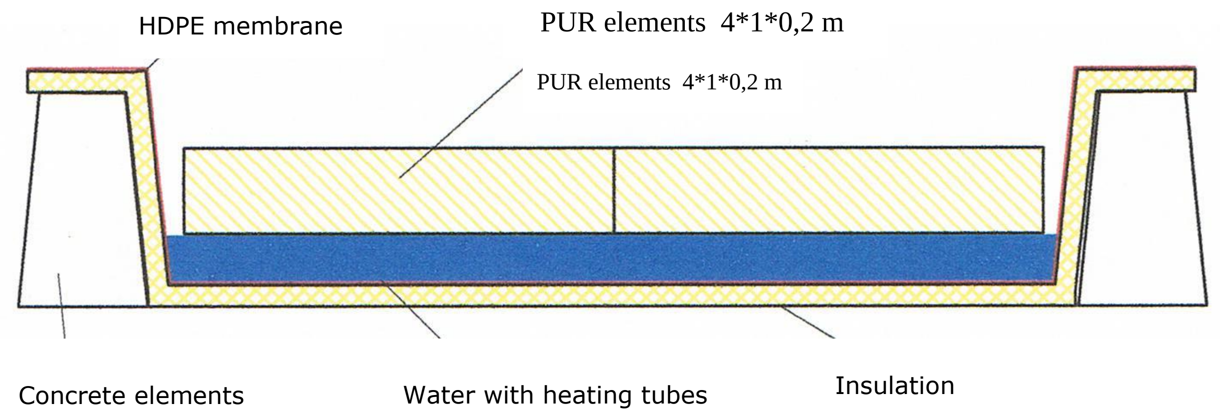

Figure 7: *Test basin for PUR elements. STEEL-solution (Ref. 2)*

The result of this test, which were going on for app. four months were positive. The elongation of the
elements when heated from 20° to 60° C. on one side is between 1 and 3 o/oo and no change of form is visible. It seems that the coating is able to stabilize the form and to prevent unwanted curving.

Water vapour resistance.
Simultaneously with the experiment above two elements – one with coating and one without - floating in the same basin have been taken from the basin at regular intervals and weighed. This way the vapour diffusion from the hot water could be assessed. The coated element gained app. 40 g/(m2*day). This figure is much improved compared to the uncoated element given the same conditions (app. 80 g/(m2*day)). This shows that the polyurea coating has a higher water vapour resistance than the PUR foam itself.
A sample of the coating has been tested for vapour diffusion at high temperatures (80° C.) by the Danish Institute of Technology. The test was carried out according to DS/EN 12086,

1999 with direct water contact at one side and 50 and 80% relative humidity on the other side of the sample. (corresponding to ASTM E96 – inverted water). The diffusion became constant after a few days and the value was measured to 289 g/(m2*day) for 50 % RH and 110 g/(m2*day) for 80 % RH. This test is seen to be consistent with the figures above when it is taken into consideration that the relative humidity between the coating and the foam quickly becomes high – the figures indicate that this humidity correspond to 85-90 % RH in air.
Even this improved resistance is however not satisfactory as it would mean an addition of about 50 kg of water per m2 in the run of 10 years (assuming that the temperature impact of the varying temperatures in the top of the storage corresponds to 4 month of constant exposure with 80° C.). The diffusion is likely to decrease as the wet layer at the bottom grows thicker, but this effect is difficult to assess in any short term measurements.
This means that the elements either must be changed at relatively short intervals (5 years?) or must be made thicker from the beginning to compensate for the loss of temperature resistance.

As neither of these options were satisfactory for Marstal District Heating further tests were carried out in the last months of 2011:

a) Use of other types of polyurea coating with improved water vapour resistance
b) Use of aluminium foil between the coating and the foam.
c) Use of 0,5 mm aluminium sheets for the bottom part of the elements.

Ad a: Testing on small samples (app. 0,2 m2) resulted in a decrease in water intake of about 20%. This method was given up as no further improvements seemed possible.

Ad b: Tests on similar samples where the glass fibre was changed to aluminium foil (0,015 mm) shoved further decrease in water intake (about 50%). The reason why the intake was not stopped completely by the aluminium was that the element was not properly sealed at the top. The test was discontinued at the following reasons: 1. The aluminium foil shoved clear signs of corrosion after 1 month of exposure. 2. It was difficult to ensure proper adhesion between the coat and the foil. 3. An alternative design using 0,5 mm aluminium sheet instead of coating was found not to be more expensive.

Ad c. As expected the use of aluminium sheet for the bottom part of the elements stopped the water intake completely.

On this background option c was considered further. The Danish Institute for Corrosion was asked to assess the solution, and stated that it was likely to withstand the temperatures in question for 20 years provided that the thickness of the sheet was increased to 0,75 mm. The reason for this recommendation was the risk for pit corrosion due to the high temperatures.

Detailed solutions on various design problems like the fastening to the borders, the connection between the foam elements, etc. were now discussed, but in the final analysis the PUR-foam solution was given up because of lack of funds and time to arrive at a complete and proven solution of all problems including the establishment of production facilities for the elements.

Fig. 8 below illustrates the latest design of the lid (end of 2011). The floating elements each sized app. 2*6 meters are coated at the bottom part (app. 120 mm) with 0,8 mm aluminium sheet and at the top part (app. 80 mm) with polyurea coat. The elements are joined by slabs of glass fibre coated with polyurea. At the border a gab of about 200 mm allows for as well thermal expansion of the lid as movements due to tangential wind forces. The lid is fastened with EPDM straps, about 100 at each side.

The maximum tangential wind force has been calculated to 40 kN. (Average wind speed: 24 m/s, height above terrain: 5 m). Different combinations of temperature expansion and wind speed has been considered and forces in the single straps of between 0,1 and 1 kN has been found.

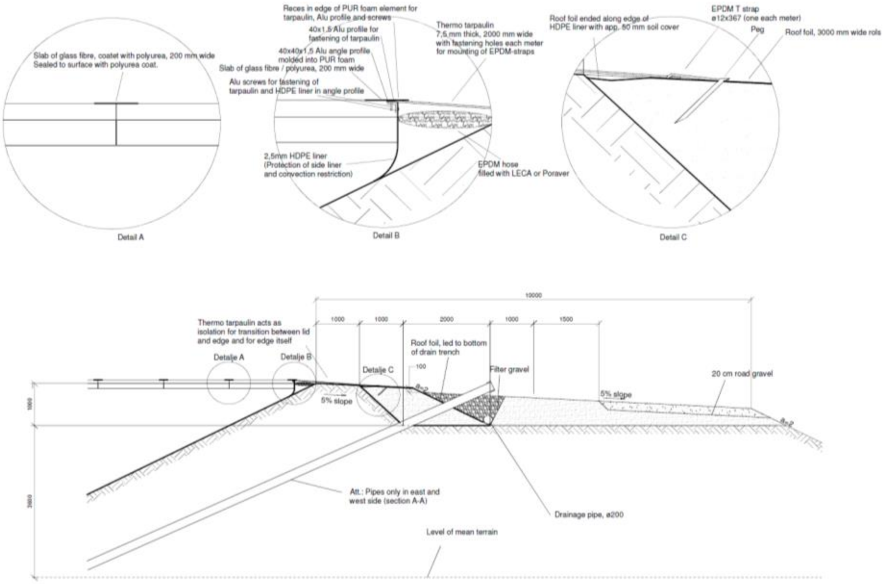

Figure 8: *Section view of the edge of the storage. STEEL-solution (Ref. 2)*

The price for the STEEL-solution is for the 75,000 m^3 storage in Marstal (88 x 113 m)

Floating cover incl. implementation	768,600 €
Edge solution incl. implementation	129.600 €
Total	898,200 €
Price/m^2	90 €

The prices are calculated by STEEL. Price for implementation is very rough since no experiences are available.

The construction can follow the water level for a 16 meter deep 75,000 m^3 storage, but for a deeper storage this will only partly be possible, because the top of the cover has to be in a higher level than the edge of the storage to get the lid of rain water.

Also tightness of assemblance of elements and stiffness of construction is not tested. After development of the STEEL-solution corrosion was recognised in the 75,000 m^3 Marstal storage. Therefore Ph is now raised to 9.8. That will cause corrosion in aluminium and the STEEL solution then has to be with stainless steel and thus more expensive.

1.5.3 DC-system solution

DC-system is a Danish supplier of thermo panels. The panels are made of PUR formed between stainless steel plates, galvanized steel plates or aluminium plates.

DC-system has made an offer for a new floating cover for the pilot storage. The offer includes:

- Panels with cast-in locking system. Size 0,2x6x1,2 m
- Surface is galvanized steel with 25 micron silicone polyester, and stainless steel to the water side
- U-value 0.115 W/m-k
- Butyl rubber strips for assemblance of panels to the water side

Plan and section of the panels are shown in Figure 9.

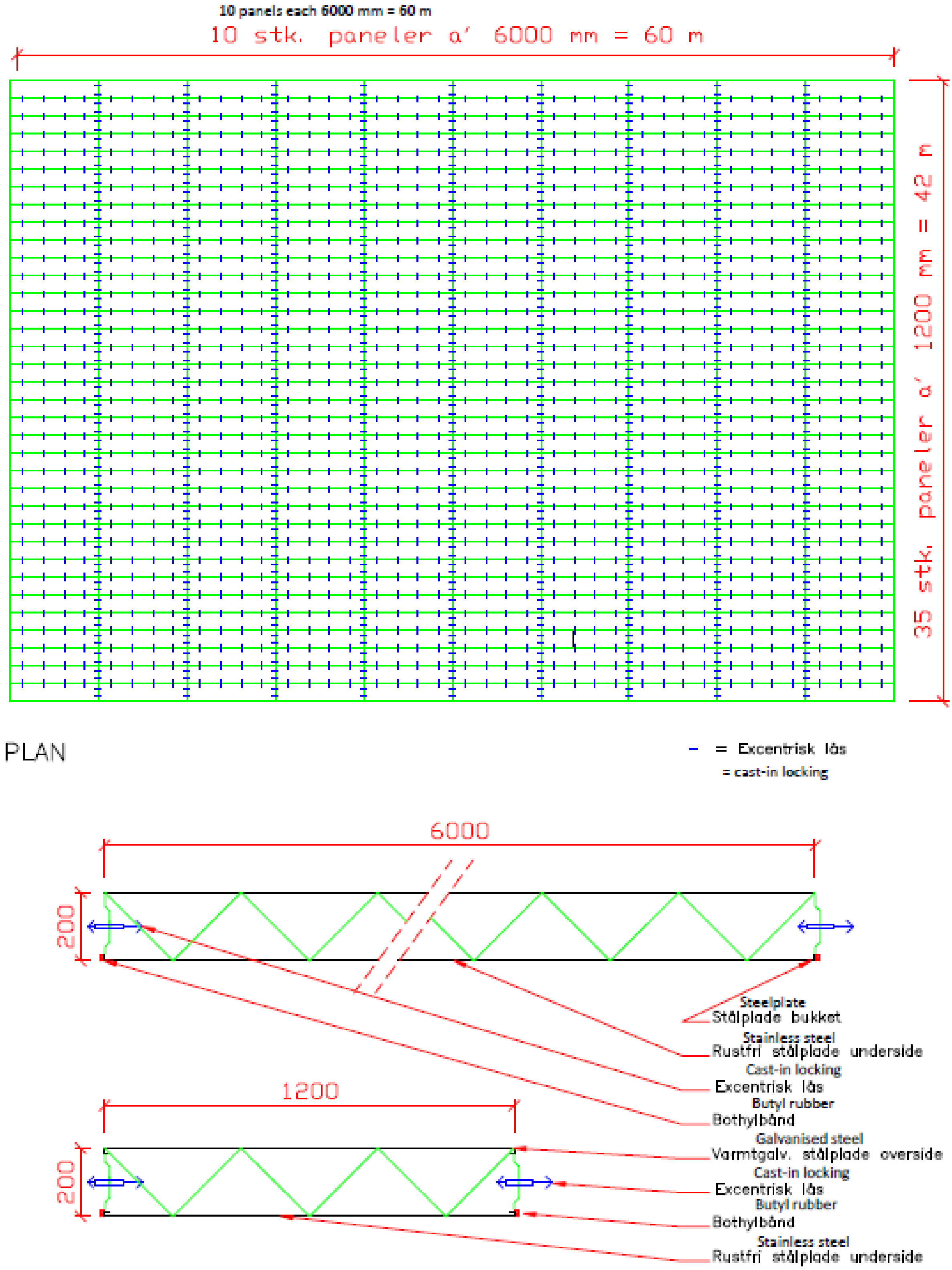

***Figure 9:** GSE lid design, first proposal*

The DC-system-solution has, as the STEEL-solution to be fastened with EPDM straps.

The DC-system-solution is similar to the cover solution in a 1,500 m^3 test storage in Ottrup-gård. This test storage has been in function since 1996 without having problems with air pockets or puddles of water. The test storage at Ottrupgård has sides of each 25 meters length, but a full scale storage will have 100 meters or more as side length. Therefore a calculation and maybe a test has to show if the construction is stiff enough to resist air pockets and puddles of water in a full scale version.

The prices are calculated by DC-System for the 10,000 m^3 pilot storage in Marstal (42x64.8 m). The price for the elements is app. 200,000 € and 67,000 € for the mounting or 98.1 €/m^2. It is estimated, that an edge solution similar to the edge solution for STEEL is necessary. If the m^2 price for the cover is the same for the full scale storage in Marstal (88 x 113 m) the price will be

Cover incl. implementation	975.500 €
Edge solution incl implementation	129.600 €
Total	1.105.100 €
Price/m^2	111 €

The price might be lower/m^2 for the full scale storage because of the higher amount of elements.

The long term temperature resistance of butyl rubber in the assemblence system and stiffness of the construction for full scale storages has to be tested.

The construction can follow the water level for a 16 meter deep 75,000 m^3 storage, but for a deeper storage this will only partly be possible because the top of the cover has to be in a higher level than the edge of the storage to get rid of rain water.

1.5.4 SPU-solution

SPU is a Finnish supplier of standard PUR-elements for insulation. The elements can be combined to a cover solution as shown in Figure 10-15.

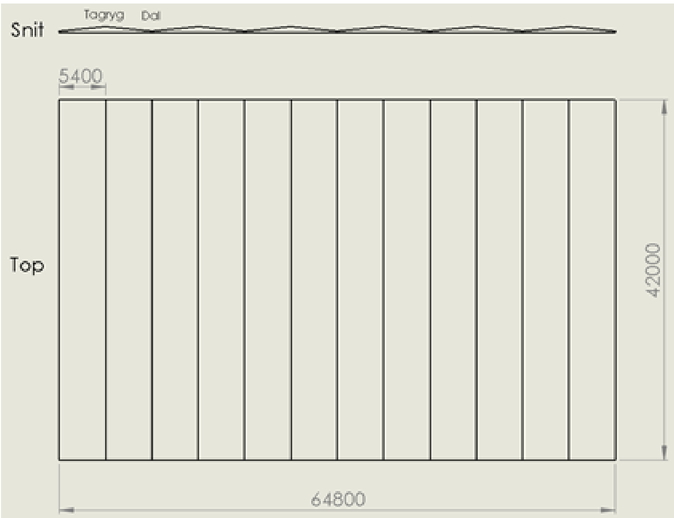

Figure 10: *Ground plan of cover with six "roof edges" and valleys. The valleys are drainage channels. Every section of 5400 mm consist of similar elements except the edges where the upper element serves as water outlet. SPU-solution.*

Figure 11: *Cross-section. SPU-solution.*

Figure 12: *Cross section with the two sections near the edge. SPU-solution.*

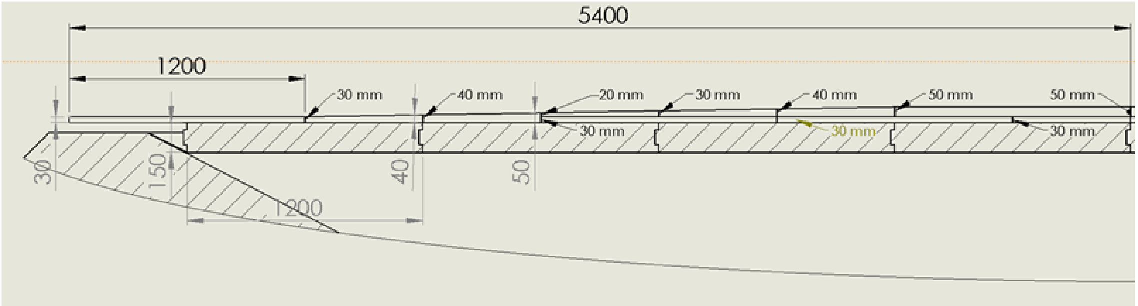

Figure 13: *Cross-section showing ½ section with level and sphenoid PUR-elements. SPU-solution.*

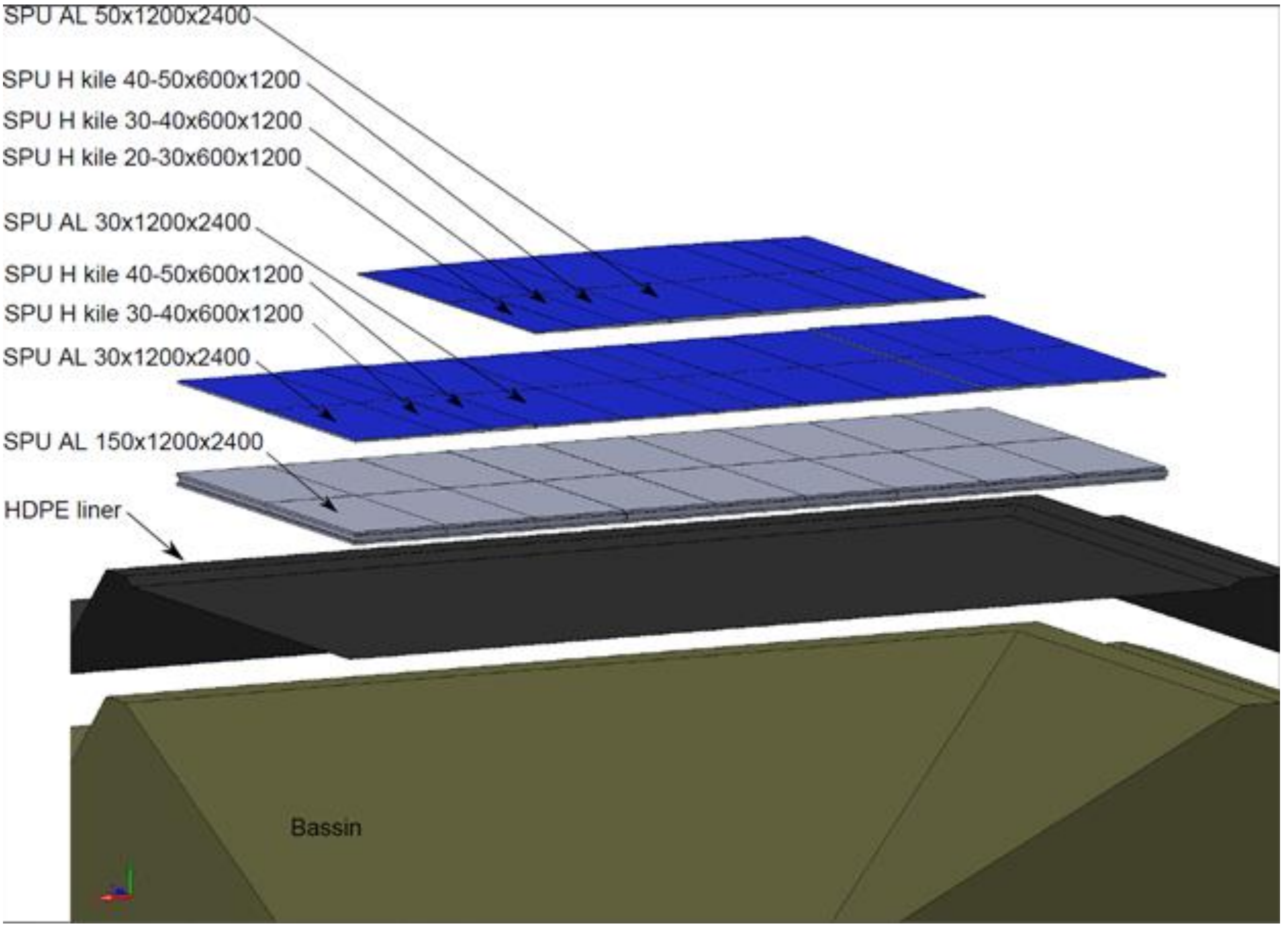

Figure 14: *Levels and elements in the SPU-solution. The HDPE-liner can be avoided if the assemblance between the PUR-elements is tight on the water side.*

The SPU-solution has as the STEEL-solution to be fastened with EPDM straps.

The price for the PUR elements is calculated by SPU and the price for mounting is calculated by PBJ Miljø for the 10,000 m^3 pilot storage in Marstal (42 x 64.8 m^2). The price for the elements is app. 89,000 € and the price for the mounting is app. 61,500 €. That gives a total price of 55,4 €/m^2 incl. mounting.

If the m^2 for the cover is the same for the full scale storage in Marstal (88 x 113 m^2) the price will be:

Cover incl. implementation	550,900 €
Edge solution incl. implementation	129,600 €
Cover liner	153,900 €
Total	834,400 €
Price/m^2	84 €

If the assemblence between the elements are tight to the water side, the cover liner can be avoided, and the price will be 78 €/m^2.

The price might be lower/m^2 for the full scale storage because of the higher amount of elements.

Tightness of assemblances and stiffness of the construction has to be tested.

The construction without cover liner can follow the water level for a 16 meter deep 75,000 m^3 storage, but for a deeper storage this will only partly be possible, because the top of the cover has to in a higher level than the efte of the storage to get rid of rain water.

After development of the STEEL-solution corrosion was recognized in the 75,000 m^3 Marstal storage. Therefore Ph is now raised to 9.8. That will cause corrosion in aluminium and the SPU-solution has then to be with stainless steel and thus more expensive.

For the DC-system solution the difference between aluminium and stainless steel is 20.5€/m^2.

1.5.5 Dissemination of results

During the project, there has been a continuously exchange of results with the projects SUNSTORE 3 in Dronninglund and SUNSTORE 4 in Marstal.

External dissemination to Danish and European partners has taken place through these two projects and through the projects:

- SDH Plus (to stakeholders in Europe) and
- IEA Task 45 (to stakeholders in the IEA Solar Heating and Cooling Program).

1.6 Utilization of project results

Since none of the designs were implemented, the project results have not been utilized as expected in a demonstration, but the project has resulted in new cover designs, that will be further developed in the ongoing projects in Vojens and Gram (LECA-solution) and in future projects in- and outside Denmark.

1.7 Project conclusion and perspective

The solutions and prices for the solutions are:

Solution	Estimated price/m^2, full scale
LECA. Leca is placed on a cover liner. Top with Rockwoll and top membrane	96
STEEL. Special elements of PUR surrounded with aluminium is assembled and floating on the water	90
DC-System. Standard elements of PUR and covered with stainless steel on the water side is assembled and floating on the water	111
SPU. Standard elements of PUR is combined to a floating construction placed on a cover line	84

None of the constructions has been tested in pilot or full scale, but during the project corrosion was found in the pipes in the 75,000 m^3 storage in Marstal. To prevent further corrosion Ph has been raised to 9.8. That means the aluminium based solutions will be corroded and the aluminium in these constructions has to be changed to stainless steel. That might raise the price with app. 20 €/m^2. Thus the prices for the PUR solutions will be in the same level.

Taken that info account, the DC-System-Solution is most promising for further investigations. Also the LECA-solution can be interesting. But it has a couple of disadvantages: [1)] The cover is constructed for a fixed water level and [2)] if air condition in the LECA insulation does not function as expected, there will be a risk of diffusion of water vapour into the LECA insulation.

References

1. Final Technical Report, SUNSTORE 2. PlanEnergi 2004.
2. Design of the pit heat storage. Deliverable D.2.2, SUNSTORE 4. PlanEnergi 2013.
3. SUNSTORE 3, Fase 1, projektering og udbud. PlanEnergi m.fl. 2011

Annex

Relevant links

www.sunstore4.eu (SUNSTORE 4)

www.solar-district-heating.eu (SDH Plus)

www.task45.iea-shc.org (IEA Task 45) hcstuven@gmail.com