Storage of thermal energy for reuse

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Abstract

Osaka Gas Co., Ltd., was asking for a novel thermal storage technique, or material. This should meet the requirements of: Having a thermal storage density of 400 KJ/L, and be usable in the temperature range from 0 to 150 degrees Celsius.

There are two possible ways to reach those thermal energy storage density’s, chemical storage and thermal storage. In this last one the distinction can be made in: Sensible- and Latent heat. Both possibility’s has it pro’s and con’s, like stability and reactivity, but latent heat gives the most advantages.

By taking all those restrictions in account, the most suitable material is: Barium Hydroxide octahydrate.

There were no further requirements made by Osaka Gas Co., Ltd., about the applicability, so the Client said that a “Exchanging and storage devices” needed to be designed. The main goal of this device is that it stores the heat produced by a fuel cell, and releases later on to tap water for use in a house hold.

To design the device, first the total volume needed to store the amount of heat produced in a day should be calculated. Next the heat exchanging surface to heat up the tap water will be calculated. Which eventually then leads to the dimensions of the device.

And finally this leads to the cost and selling prices of the apparatus, but before setting a selling price can set, the market should be known. This is approximate 0,5% of all Dutch households. Overall the project will have a payback time of 7 years, and will provide a profit of 21 million dollars in ten years’ time.

Altogether the project is viable, but to make this project even more viable after 10 years, it will require new technologies and new ideas to transform and improve the heat storage to be able to attract new users.
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# Nomenclature

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<th>Symbol</th>
<th>Explanation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Surface</td>
<td>m²</td>
</tr>
<tr>
<td>Cp</td>
<td>Heat capacity</td>
<td>J/Kg*K</td>
</tr>
<tr>
<td>dT</td>
<td>Difference in temperature</td>
<td>C°</td>
</tr>
<tr>
<td>dx</td>
<td>Difference in the x direction</td>
<td>M</td>
</tr>
<tr>
<td>F</td>
<td>Volumetric flow</td>
<td>m³/s</td>
</tr>
<tr>
<td>F&lt;sub&gt;tap water&lt;/sub&gt;</td>
<td>Volumetric flow of tap water</td>
<td>m³/s</td>
</tr>
<tr>
<td>J&lt;sub&gt;x&lt;/sub&gt;</td>
<td>Heat flow in direction x</td>
<td>j/s</td>
</tr>
<tr>
<td>Q&lt;sub&gt;to cool&lt;/sub&gt;</td>
<td>Heat flow to heat up the Barium Hydroxide octahydrate</td>
<td>j/s</td>
</tr>
<tr>
<td>Q&lt;sub&gt;to heat&lt;/sub&gt;</td>
<td>Heat flow to heat up the tap water flow</td>
<td>j/s</td>
</tr>
<tr>
<td>T&lt;sub&gt;in&lt;/sub&gt;</td>
<td>Temperature of the inlet</td>
<td>C°</td>
</tr>
<tr>
<td>T&lt;sub&gt;out&lt;/sub&gt;</td>
<td>Temperature of the outlet</td>
<td>C°</td>
</tr>
<tr>
<td>T&lt;sub&gt;storage&lt;/sub&gt;</td>
<td>Temperature of the storage compartment</td>
<td>C°</td>
</tr>
<tr>
<td>V&lt;sub&gt;storage&lt;/sub&gt;</td>
<td>Volume of the storage compartment</td>
<td>L</td>
</tr>
<tr>
<td>V&lt;sub&gt;total&lt;/sub&gt;</td>
<td>Total volume</td>
<td>m³</td>
</tr>
<tr>
<td>λ</td>
<td>Heat resistance</td>
<td>W/m*K</td>
</tr>
<tr>
<td>ρ</td>
<td>Density</td>
<td>Kg/m³</td>
</tr>
</tbody>
</table>
1. Objective
The present work is a proposal for the request from Osaka Gas Co., Ltd., an energy company in Japan. The company is seeking a commercial way to store the heat generated in fuel cells, to reuse it for water heating in the residence where the fuel cell is installed.

The product requirements are a thermal storage density of at least 400 kJ/L, a temperature range from 0 to 150 ºC, and a long-term durability. In the beginning of this proposal, a brief introduction on different possibilities for heat storage will be given. Then, the most suitable option will be chosen, followed by the heat exchange unit design and the economic viability study.
2. Introduction and material selection

Thermal energy can be stored as a change in internal energy of a material as sensible heat, latent heat and thermochemical or combination of these. These possibilities are shown in Figure 1.

![Diagram of thermal energy storage](image)

Figure 1 Different types of thermal storage

The use of sensible heat is probably the simplest way to store thermal energy. The amount of heat stored depends on the specific heat and mass of the material and its change in temperature. Water seems to be the best liquid media, due to its availability and high specific heat. For solid media, rocks and bricks are usually applied for air heating. However, the specific heat is generally much lower than latent heat and heat of reaction, what makes its use limited. In this project, none material could provide the energy density required (400 kJ/L) just with sensible heat.

In the “chemical” group, heat pumps are used for heating or cooling environments, therefore is not appropriate for this water heating project. The use of the heat of reaction consists in taking advantage of the endothermic path to store the heat, and the exothermic to release it, heating the water, for example. The heat stored depends on the amount of storage material, the endothermic heat of reaction, and the extent of conversion. These two last variables are highly dependent on the temperature, representing an additional issue for the system control.

The latent heat storage consists in use the heat that a material absorbs to change its phase. The phase changes can be solid-solid, solid-liquid, solid-gaseous and liquid-gaseous. In solid–solid transitions, heat is stored as the material is transformed from one crystalline to another. These transitions generally have small latent heat and small volume changes than solid–liquid transition. The advantage is that the material volume remains almost the same. Liquid-gaseous and solid-gaseous transitions have a high latent heat in general, however, the huge expansion in the volume of gas phase make it unsuitable for commercial applications in water heating. Solid-liquid transition has a relatively smaller latent heat, but the smaller change in volume makes it economic viable.
The material used for latent heat storage is called phase change material (PCM). Basically, the energy coming from the fuel cell is used to melt the PCM. As the melting process is endothermic, it absorbs the energy. When the PCM solidifies again, it releases the energy. With an appropriated heat exchange system, which is the aim of this project, this energy released is used to heat the water.

In order to be suitable for commercial applications, some properties for a PCM are required:

- The operating temperature of the heating or cooling should be matched to the transition temperature of the PCM. The latent heat should be as high as possible, especially on a volumetric basis, to minimize the physical size of the heat store. High thermal conductivity would assist the charging and discharging of the energy storage.
- Phase stability during freezing melting would help towards setting heat storage and high density is desirable to allow a smaller size of storage container. Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem.
- Supercooling has been a troublesome aspect of PCM development, particularly for salt hydrates. Supercooling of more than a few degrees will interfere with proper heat extraction from the store, and 5–10 °C supercooling can prevent it entirely.
- PCM can suffer from degradation by loss of water of hydration, chemical decomposition or incompatibility with materials of construction. PCMs should be non-toxic, nonflammable and non-explosive for safety.
- Low cost and large-scale availability of the phase change materials is also very important

The PCMs can be divided in three groups: organic, inorganic and eutectic. Organic PCMs cover paraffins and non-paraffins. Paraffins are mixture of straight chain n-alkanes. The melting point and heat of fusion increase with the chain length. They are available in a large temperature range and have long freeze-melt cycle. Non-paraffin is the largest category of PCMs. These materials differ widely in their properties but, in general, inflammability and low vapor pressure can be expected. Therefore, they are indicated only for low temperature applications.

The inorganic PCMs are mostly salt hydrates, which are crystalline solids of general formula AB.nH₂O. The solid–liquid transformation of salt hydrates is actually a dehydration of hydration of the salt, although this process resembles melting or freezing thermodynamically. In the melting point, salt hydrates breakup into anhydrous salt and water or into a lower hydrate and water. The issues to be faced by salt hydrates as PCMs are:

- Incongruent melting: occurs when the salt is not entirely soluble in its water of hydration at the melting point, resulting in a supersaturated solution. The solid salt, due to its higher density, settles down at the bottom of the container and is unavailable for recombination with water during the reverse process of freezing. It can be overcome with mechanical stirring, adding excess of water or adding a thickening agent to prevent the salt of settling.
- Supercooling: At the fusion temperature, the rate of nucleation is generally very low. To achieve a reasonable rate of nucleation, the solution has to be supercooled and hence energy instead of being discharged at fusion temperature is discharged at much lower temperature. In order to prevent supercooling and incongruent melting, General Electrics developed a horizontal cylindrical vessel with a rotation rate of 3 rpm.
Overcome these problems, salt hydrates are the most important PCMs. They have been largely studied due to their high latent heat of fusion per unit volume, a thermal conductivity two times higher than paraffins, and small volume changes. The Table 1 below shows a list of salt hydrates with their respective melting point and latent heat.

<table>
<thead>
<tr>
<th>Material</th>
<th>Melting point (°C)</th>
<th>Latent heat (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K$_2$HPO$_4$·6H$_2$O</td>
<td>14.0</td>
<td>109</td>
</tr>
<tr>
<td>FeBr$_3$·6H$_2$O</td>
<td>21.0</td>
<td>105</td>
</tr>
<tr>
<td>Mn(NO$_3$)$_2$·6H$_2$O</td>
<td>25.5</td>
<td>148</td>
</tr>
<tr>
<td>FeBr$_3$·6H$_2$O</td>
<td>27.0</td>
<td>105</td>
</tr>
<tr>
<td>CaCl$_2$·12H$_2$O</td>
<td>29.8</td>
<td>174</td>
</tr>
<tr>
<td>LiNO$_3$·2H$_2$O</td>
<td>30.0</td>
<td>296</td>
</tr>
<tr>
<td>LiNO$_3$·3H$_2$O</td>
<td>30.0</td>
<td>189</td>
</tr>
<tr>
<td>Na$_2$CO$_3$·10H$_2$O</td>
<td>32.0</td>
<td>267</td>
</tr>
<tr>
<td>Na$_2$SO$_4$·10H$_2$O</td>
<td>32.4</td>
<td>241</td>
</tr>
<tr>
<td>KFe(SO$_4$)$_2$·12H$_2$O</td>
<td>33</td>
<td>173</td>
</tr>
<tr>
<td>CaBr$_2$·6H$_2$O</td>
<td>34.0</td>
<td>138</td>
</tr>
<tr>
<td>LiBr$_2$·2H$_2$O</td>
<td>34.0</td>
<td>124</td>
</tr>
<tr>
<td>Zn(NO$_3$)$_2$·6H$_2$O</td>
<td>36.1</td>
<td>134</td>
</tr>
<tr>
<td>FeCl$_3$·6H$_2$O</td>
<td>37.0</td>
<td>223</td>
</tr>
<tr>
<td>Mn(NO$_3$)$_2$·4H$_2$O</td>
<td>37.1</td>
<td>115</td>
</tr>
<tr>
<td>Na$_2$HPO$_4$·12H$_2$O</td>
<td>40.0</td>
<td>279</td>
</tr>
<tr>
<td>CoSO$_4$·7H$_2$O</td>
<td>40.7</td>
<td>170</td>
</tr>
<tr>
<td>KF·2H$_2$O</td>
<td>42.0</td>
<td>162</td>
</tr>
<tr>
<td>Mg$_2$·8H$_2$O</td>
<td>42.0</td>
<td>133</td>
</tr>
<tr>
<td>Ca$_2$·6H$_2$O</td>
<td>42.0</td>
<td>162</td>
</tr>
<tr>
<td>K$_2$HPO$_4$·7H$_2$O</td>
<td>45.0</td>
<td>145</td>
</tr>
<tr>
<td>Zn(NO$_3$)$_2$·4H$_2$O</td>
<td>45</td>
<td>110</td>
</tr>
<tr>
<td>Mg(NO$_3$)$_2$·4H$_2$O</td>
<td>47.0</td>
<td>142</td>
</tr>
<tr>
<td>Ca(NO$_3$)$_2$·4H$_2$O</td>
<td>47.0</td>
<td>153</td>
</tr>
<tr>
<td>Fe(NO$_3$)$_3$·9H$_2$O</td>
<td>47</td>
<td>155</td>
</tr>
<tr>
<td>Na$_2$SiO$_3$·4H$_2$O</td>
<td>48</td>
<td>168</td>
</tr>
<tr>
<td>K$_2$HPO$_4$·3H$_2$O</td>
<td>48</td>
<td>99</td>
</tr>
<tr>
<td>Na$_2$S$_2$O$_5$·5H$_2$O</td>
<td>48.5</td>
<td>210</td>
</tr>
<tr>
<td>MgSO$_4$·7H$_2$O</td>
<td>48.5</td>
<td>202</td>
</tr>
<tr>
<td>Ca(NO$_3$)$_2$·3H$_2$O</td>
<td>51</td>
<td>104</td>
</tr>
<tr>
<td>Zn(NO$_3$)$_2$·2H$_2$O</td>
<td>55</td>
<td>68</td>
</tr>
<tr>
<td>FeCl$_3$·2H$_2$O</td>
<td>56.0</td>
<td>90</td>
</tr>
<tr>
<td>Ni(NO$_3$)$_2$·6H$_2$O</td>
<td>57.0</td>
<td>169</td>
</tr>
<tr>
<td>MnCl$_2$·4H$_2$O</td>
<td>58.0</td>
<td>151</td>
</tr>
<tr>
<td>MgCl$_2$·4H$_2$O</td>
<td>58.0</td>
<td>178</td>
</tr>
<tr>
<td>CH$_3$COONa·3H$_2$O</td>
<td>58.0</td>
<td>265</td>
</tr>
<tr>
<td>Fe(NO$_3$)$_3$·6H$_2$O</td>
<td>60.5</td>
<td>126</td>
</tr>
<tr>
<td>NaAl(SO$_4$)$_2$·10H$_2$O</td>
<td>61.0</td>
<td>181</td>
</tr>
<tr>
<td>NaOH·H$_2$O</td>
<td>64.3</td>
<td>273</td>
</tr>
<tr>
<td>Na$_2$PO$_4$·12H$_2$O</td>
<td>65.0</td>
<td>190</td>
</tr>
<tr>
<td>LiCH$_3$COO·2H$_2$O</td>
<td>70.0</td>
<td>150</td>
</tr>
<tr>
<td>Al(NO$_3$)$_3$·9H$_2$O</td>
<td>72.0</td>
<td>155</td>
</tr>
<tr>
<td>Ba(OH)$_2$·8H$_2$O</td>
<td>78.0</td>
<td>265</td>
</tr>
<tr>
<td>Mg(NO$_3$)$_2$·6H$_2$O</td>
<td>89.9</td>
<td>167</td>
</tr>
</tbody>
</table>

The eutectics PCMs are combinations of the groups explained above made to adjust the properties for specific applications. The only group where can be found a PCM that meet the energy density required for this project is the hydrate salt. After a screening process, taking in consideration the
project specification and the properties desired for PCMs in general, barium hydroxide octahydrate \( \text{Ba(OH)}_2\cdot8\text{H}_2\text{O} \) was chosen as the PCM for this project.

Barium hydroxide octahydrate has a melting point of 78 °C, density of 2180 kg/m³ and an energy storage density around 630 kJ/L. Jing Li, Zhongliang Liu and Chongfang Ma proceeded experiments to attest the suitability of \( \text{Ba(OH)}_2\cdot8\text{H}_2\text{O} \) as a PCM. After 500 thermal cycles, no phase segregation nor super cooling were noticed. The results are shown in Table 2 [2].

<table>
<thead>
<tr>
<th>No. of test cycles</th>
<th>Melting temperature (°C)</th>
<th>Latent heat of fusion (kJ/kg)</th>
<th>Volumetric storage density (J/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>78</td>
<td>288.6</td>
<td>629.15</td>
</tr>
<tr>
<td>160</td>
<td>77.9</td>
<td>286.1</td>
<td>623.70</td>
</tr>
<tr>
<td>230</td>
<td>77.7</td>
<td>285.1</td>
<td>621.52</td>
</tr>
<tr>
<td>330</td>
<td>77.6</td>
<td>284.6</td>
<td>620.43</td>
</tr>
<tr>
<td>500</td>
<td>77.6</td>
<td>285.6</td>
<td>622.61</td>
</tr>
</tbody>
</table>

Therefore, barium hydroxide octahydrate has good thermal reliability. If the material is well sealed and measures are set up to prevent its toxicity, then barium hydroxide octahydrate can be commercially explored.
3. Designing the heat storage- and exchanging device

Now the material where to store the (heat) energy in is known (Barium hydroxide octahydrate), the heat storage- and exchanging apparatus can be designed. The major points where the apparatus need to comply with are:

- Storing the heat produced in 1 day by the fuel cell
- Provide heated water with a flow rate of 6 l/min at 60 degree Celsius
- Be as efficient as possible, in the way of space, heat transfer, cost and so on

3.1 Produced heat by the fuel cell
So first the specifications of the fuel cell needed to be present:

- Maximal power production 700W
- Maximal power efficiency 38,5%
- Heat production 55,5%
- Waste heat 6%

This leads to a heat production of 1009 J/s what is 87 million joule of heat energy a day that needs to be stored in the Barium hydroxide octahydrate. The specifications for the amount of heat stored of the said material are in the best case about 630 kJ/l, while the initial design asks for a material of 400kJ/l. So the best case scenario is over specified, but it is the best case. Therefore an average of the best case scenario and the design specifications were taken. That is approximate 525J/l, which gives that a volume of 166,07 litres of Barium Hydroxide octahydrate is needed to store a day of heat which has been produced by the fuel cell.

3.2 Start of the designing
Now the amount of heat that needs to be stored and the volume where in it needs to be stored are known, the theoretical device can be designed. In order to do that, first a schematic drawing is made.

3.2.1 Schematic drawing of the heat storage- and exchanging device

In the drawing there can be seen that it is an “3-way” like heat exchanger, with a heat storage capacity. Further some known important parameters are shown, these are $T_{in}$, $T_{out}$, $F_{tap}$, $T_{storage}$ and $V_{storage}$. The parameters $Q_{to\ heat}$ and $Q_{to\ cool}$, must be calculated. And $dx$ is a parameter to tune the efficiency of the apparatus.
3.2.2 Heat flow needed to heat the tap water to 60 degree Celsius

In order to calculate the heat flow needed to heat up the incoming flow of tap water to a preferable 60 degree Celsius, the following equation is used:

\[ Q_{\text{to heat}} = F \cdot \rho \cdot C_p \cdot (T_{\text{out}} - T_{\text{in}}) \]  \hspace{1cm} (3-1)

Where in the parameters are:

- \( F \) = Flow of tap water \hspace{1cm} 6 L/min, 0.1 L/s
- \( \rho \) = Density of water \hspace{1cm} 999 kg/m³, 0.999 kg/l
- \( C_p \) = Heat capacity of water \hspace{1cm} 4181,3 J/kg*K
- \( T_{\text{out}} \) = desired water temperature \hspace{1cm} 60 °C
- \( T_{\text{in}} \) = Water temperature from the water main \hspace{1cm} approx. 10 °C

Substituting gives that the heat flow from the storage material to the water needed to be \( Q_{\text{to heat}} = 20906,5 \) J/s. At an outflow from the water, at 60 °C and 6 L/min.

3.2.3 The acreage needed to reach \( Q_{\text{to heat}} \)

To calculate the required surface for exchanging heat between the storage and tap water the law of Fourier can be applied.

\[ \frac{J_x}{A} = -\lambda \frac{dT}{dx} \]  \hspace{1cm} (3-2)

Where in the parameters are:

- \( J_x \) = Heat flow in direction x \hspace{1cm} 20906,5 J/s
- \( A \) = Surface of heat exchanging \hspace{1cm} ? m²
- \( \lambda \) = Heat resistance \hspace{1cm} 0.66 W/m*K
- \( \frac{dT}{dx} \) = Temperature gradient \hspace{1cm} K/m

\(-\) = negative sign, which indicates that the heat flow is from hot to cold. This sign will be further on be neglected.

Rearranging equation (3-2) gives:

\[ \frac{J_x}{\lambda \frac{dT}{dx}} = A \]  \hspace{1cm} (3-3)

Now the surface needed to exchange the heat can be calculated when the temperature gradient is known. Therefor the assumption is made that \( dT \) is a constant and \( dx \) is the thickness of the storage material. So \( dT \) is 50 °C and \( dx \) is 0.00809 m, what gives a gradient of: 6180,47 K/m.

With this data the needed acreage of the heat exchanger can be calculated, and gives that a surface A of 5,13 m² is required for a flow of 6 L/min at 60 °C.
3.2.4 Checking the volume

With the known surface and thickness of the storage material can be calculated if the necessary volume have been met, by use of equation (3-4):

\[ V = A \cdot dx \]  \hspace{1cm} (3-4)

With:

\[ A = \text{Surface} \quad 5,13 \text{ m}^2 \]

\[ dx = \text{thickness of the storage material} \quad 0,00809 \text{ m} \]

That gives that \( V = 41.46 \text{ L} \), while in 3.1 is calculated that a volume of 166,07 L was needed. By common sense it looks like that \( V \) is almost a quarter of the volume needed, this can we check by (3-5):

\[ \frac{V}{V_{\text{total}}} = \sim 0.25 = \frac{41.46}{166.07} = 0.24967767 \sim 0,25 \]  \hspace{1cm} (3-5)

So that means that at a \( dx \) of 0.00809 a surface of 4 times \( A \ 5,13\text{m}^2 \ (20,50 \text{m}^2) \) is needed to reach the desired volume. Another potion could be increasing \( dx \), to reach the wanted volume. But by increasing \( dx \) the driving force \( \frac{dT}{dx} \) will decrease, which leads to an increase of the surface needed.

3.2.5 Other assumptions made

In designing the heat storage- and exchanging devise two other assumptions are made, these are:

1. The heat flow to heat up the tap water is approximate 21 times bigger than the heat produced by the fuel cell. So \( Q_{\text{to heat}} \) is a limiting factor, and that is why it isn’t needed to prove that the flow \( Q_{\text{to cool}} \) is possible.

2. In calculating the surface of the exchanging part of the heat storage- and exchanging apparatus, the heat resistance of the material of the apparatus is neglected. This because the resistance is 10 to 20 times less than that of Barium hydroxide octahydrate.

\[ ) \] needed to be proved by experiments
3.3 Finalizing the design

In theory the heat storage and exchanging devise is designed, but the practical execution isn’t discussed. Like the way it should look like, where in a household it shall or will be placed etc.

But before there could been paid attention to, a last close look to the theoretical design is needed. As mentioned in 3.1 and 3.2.4, the device needed to have a surface big enough to “store” the total volume needed where in the energy can be stored.

The problem that will occur when using a single device, is that charging and de-charging must happen in the same time. This is fiscally impossible, because the Barium Hydroxide octahydrate will never liquefy. While this is the “power” of storing the energy.

3.3.1 Decision to be made

Amount of parts

The first practical design hurdle is about in how many pieces the device should be divided. The most logical answer to this should be, divide it in to two. A charging and de-charging part. That may be, but then the maximum energy there can be used is half of the day production. Not very economic.

So another option maybe. In 3.2.4 is shown that to reach to necessary surface and volume four of the there described units should be used. Which results in a maximum use of energy of three quarters of the day production, what is even more economic.

The amount of parts of the device could even be more increased, to get a higher efficiency. But then the material cost will probably make the device unpayable.

Physical design

The second hurdle is about the physical properties of the device. How should it look like. To reach to surface needed, a single very flat device can be designed like shown in 3.2.1. The result is than that the device is very small (like 10cm) but has a big surface (like 5.13 m²).

Another option is to stack multiple layer on top of each other, which leads to the same needed surface but the outer surface of the device will decrease. But the thickness of the device shall increase, for every time dividing the surface through a factor 2 the thickness will increase by time^2. So finally shall this design use more usable space.

Both options above are a possible choice. When choosing for the second one, a spare room or something similar is needed to place it in. What isn’t very cost effective. Therefor the first option is advisable. Because of the thinness it can be placed in whether in front of a wall or in of on top of a floor of ceiling.

Note: above described 1 of the 4 parts of the device, the final product consists of 4 parts.
### 3.3.2 The final design

Taking in account the above mentioned things leads to the final design, which is based on a very flat device with a high surface.

**Figure 3. A quick impression of the design in renders**

On the left top of the figure can be seen how flat, and tall, the device is in comparison with average human. On the right top is a detailed figure shown of the flatness of the device, in comparison with the top of an elbow.

The left bottom gives a detailed look of the device, and which compound is where. That is even more detailed in the right bottom picture, this is a cutaway picture.
3.3.3 Technical details
The technical details are given for 1 of the 4 parts of the system, all parts are equal.

**Design specifications (dimensions)**

![Figure 4. Showing the measurements of the heat storage- and exchanging device](image)

- Stainless steel 316
- Overall Dimensions 2000x2565x100mm (HxWxD)

**Note:** for additional information see Appendix A

**Design specifications (Tap water flow properties)**

- Tap water flow 0,0001 m³/s
- Tap water speed 0,0078 m/s
- Incoming temperature 10 °C
- Required out coming temperature 60 °C
- Re <= 400
- Pressure drop 0,03 Pa

**Design specifications (Storage medium)**

- Barium Hydroxide octahydrate
- Melting point 278 °C
- Set point 82 °C
- Volume 41,46 L
- Energy storage capacity 2,8 Mj
- Charging time 5,99 hours
- De-charging time 17,35 minutes

**Note:** For additional information see appendix B

**Design specifications (Heating fluid properties)**

- Incoming temperature 90 °C
- Heating fluid flow > 0,00001 m³/s
- Re <= 400
- Pressure drop < 0,03 Pa
Piping & Instruments Diagram (complete system)

Figure 5 Piping & Instruments Diagram of the complete system
3.4 Producing the system
After finally finalizing the design, the first steps towards the beginning of the production can be made. Those steps will only be briefly discussed, because it’s mainly mechanical engineering where for a mechanical engineer will be hired. But the last step of the whole production process is and will be the most important one, the quality control. To this topic some extra attention will be paid.

3.4.1 Production
Here will the production largely be discussed.

- Controlling the incoming stainless steel sheets (Quality control)
  - From each “new” batch samples will been taken and tested
- Cutting the stainless steel sheets to the desired dimensions (production)
- Welding the cut sheets to a “heat storage and exchanging device” (production)
- Placing the in and outlets (production)
- Pressure testing (quality control)
- Cleaning the device (production)
- Coating the outer walls (production)
- Removing any air from the Barium Hydroxide octahydrate compartment (production)
  - From each new batch of Barium Hydroxide octahydrate, samples will been taken and tested to control the quality (quality control)
- Filling the compartment with liquefied Barium Hydroxide octahydrate (production)
- Giving the device one heat- and cool cycle, and test the performance (quality control)
- Placing the insulation (production)
- “Ready for shipping”

3.4.2 Quality control
As mentioned there are three standard quality control points in the process of manufacturing the device. And two quality control points for checking of the delivered materials are as wanted.

Controlling the incoming stainless steel sheets
This control is a visual control, looking for dents, bumps, scratches or any other unwanted deviation.

Pressure testing
Testing of the welds made, in order to ensure that there will be no leaking’s or other kind of manufacturing faults.

Giving the device one heat- and cool cycle, and test the performance
To ensure that every device delivered requires to the said performance, a test will be performed. By heating the device up to 82 °C, and cooling down by running tap water while measuring that temperature. Which should be 60 °C

Metal sampling
Testing the metal for corrosion, and fatigue.

Sampling Barium Hydroxide octahydrate
Testing for pollution, meting point and other required tests.
3.5 Application

The heat storage and exchanging device could be used to heat up buildings when needed, or provide hot tap water when wanted. Only when the building is not located in Alaska the demand of heating a building isn’t every day. So a lot of storage devices are needed, which isn’t very economical. There for it is recommendable to use it for heating up tap water, where fore the design is optimized.

Take an average household of 4 persons with a dishwasher and a washing machine, what all are hot water consuming “devices”. To have an impression on how much hot water is consumed in a day by these “devices”, Google is consulted. This is far from scientific so no references are possible, but it gives an impression of what the minimal demands are. Just as starting point for the calculations to check of it is possible to satisfy the hot water demand. There was even some hot water left. Which leads to the following heat consumption a day:

Table 3. Overview of the possible applications of the heated water

<table>
<thead>
<tr>
<th></th>
<th>time (min)</th>
<th>times a day</th>
<th>liters needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>douche</td>
<td>12,1</td>
<td>4</td>
<td>290,4</td>
</tr>
<tr>
<td>tap water</td>
<td>10</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>dishwasher</td>
<td>2,4</td>
<td>1</td>
<td>14,4</td>
</tr>
<tr>
<td>laundry</td>
<td>8,7</td>
<td>1</td>
<td>52,2</td>
</tr>
<tr>
<td>total</td>
<td>69,5</td>
<td></td>
<td>417</td>
</tr>
</tbody>
</table>

Which is at a flow rate of six litres a minute at sixty degrees Celsius.

- Every person needs once a day a shower
- There will be used 60 litres of hot water to clean and other use
- The dishwasher has one run a day
- The laundry will be done one time a day

When more hot tap water is needed in a day, a boiler or combi-boiler is advisable as backup system.
4. Study of the Market

To be able to analyse the finances and the economic viability of the project is completely necessary estimates the number of items which would be sold.

It has been estimated that the heat storage which is designed in that project would be in 0,5% of all Netherlands homes in the next 10 year. It is equal to say that sales would be around 20.000. That number is not disproportionate taken into account the sales and the objectives of other company from the same sector ¹.

The estimated percentage of the numbers of heat storage sales is:

Table 4. Sales prediction

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>5</td>
<td>11</td>
<td>18</td>
<td>24</td>
<td>19</td>
<td>14</td>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>Sales</td>
<td>1.000</td>
<td>2.200</td>
<td>3.600</td>
<td>4.800</td>
<td>3.800</td>
<td>2.800</td>
<td>1.800</td>
<td>20.000</td>
</tr>
</tbody>
</table>

This is a prediction which tries to be realistic due to during the first years the product has to be known for the future users and the number of buyers is not very high. Then, when the project is known for almost everyone, that number of buyers increase until the most enthusiastic consumers has one in his/her own and the number of sales start to decrease again until complete de full percentage at the end of the tenth year. Obviously, the idea is that the project continue once arrive the tenth year. This idea will require new user who are not know by the moment and improvements in the project of heat storage and exchanging devices but these news users and improvement are not in the boundaries of that workshop.

This prediction of the future users has been realised for two reasons. On the one hand, it is necessary to do the annual cash flow of the economic prevision (incomes and outcomes) and to know the payback. On the other hand it is expected to provide a five years guarantee and only in that way (make a prediction on future users), the company would know how many people have to take into account for that service.
5. Financial stuff

5.1. Fabrication cost
To build the heat storage is necessary some litres of barium hydroxide octahydrate, some litres of water (which price can be omitted) and a cover of stainless steel. Then, it will be also necessary to weld the stainless steel cover and complete the installation with some exchanging devices. Prices and densities needed in 3, 4 and 5

Table 5. Materials cost

<table>
<thead>
<tr>
<th>Costs</th>
<th>Price/Unit</th>
<th>Amount</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium hydroxide octahydrate</td>
<td>$0,8/kg</td>
<td>325 kg</td>
<td>$260</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>$2,5/kg</td>
<td>2130 kg</td>
<td>$5.325</td>
</tr>
<tr>
<td>Welder</td>
<td>$30/h</td>
<td>12,5 h</td>
<td>$375</td>
</tr>
<tr>
<td>Diverse things</td>
<td>$1.000</td>
<td>-</td>
<td>$1.000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$6.960</strong></td>
</tr>
</tbody>
</table>

This is the cost to build the heat storage and exchanging devices. The sold price will be around at 30% higher than this, the final sale price will be $8.999.

5.2. Economic evaluation
The economic evaluation corresponds to the economic viability of the project. This study is based in some predictions and estimations to set the different economic items of the project. In this chapter, the outcomes and incomes will be analysed to set the finally economic viability of the project and know at what price the heat storage and exchanging devices should be sold.

To do all the computation, it has taken a limit time of ten years when it has been supposed that the sales of that product will be 20,000 units. In these ten years, there are included three year when there is not production to sell and all of the economic movement is focus on investment due at time of construction of the factory and offices. Moreover, this third year is also aimed at conducting pilot test to try to find possible systematic errors and improve performance.

Sales supposed:

Table 6. Sales prediction

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>11</td>
<td>18</td>
<td>24</td>
<td>19</td>
<td>14</td>
<td>9</td>
<td><strong>100</strong></td>
</tr>
<tr>
<td>Sales</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1000</td>
<td>2200</td>
<td>3600</td>
<td>4800</td>
<td>3800</td>
<td>2800</td>
<td>1800</td>
<td><strong>20000</strong></td>
</tr>
</tbody>
</table>

Incomes and outcomes

The incomes are the number of sold units multiplied by the price for each unit.

The outcomes are the initial investment and the costs of the services. The initial investment includes the machineries to build the heat storage and exchanging devices, the building (factory and offices),

\footnote{All of the taxes are included in all of the computations of all the project.}
the costs of conducting pilot tests and some extra costs. The service cost includes the costs related to the guarantee, costs of employment, costs of mortgage and costs of production.

All of these costs, outcomes and incomes are summarized on the tables below.

Table 7. Investment costs

<table>
<thead>
<tr>
<th>Types</th>
<th>Cost/unit</th>
<th>Units</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines</td>
<td>$4,000.000</td>
<td>1</td>
<td>$4,000.000</td>
</tr>
<tr>
<td>Buildings</td>
<td>$5,000.000</td>
<td>1</td>
<td>$5,000.000</td>
</tr>
<tr>
<td>Testing</td>
<td>$6.960</td>
<td>20</td>
<td>$139.200</td>
</tr>
<tr>
<td>Other costs</td>
<td>$1,000.000</td>
<td>1</td>
<td>$1,000.000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>$10,139,200</td>
</tr>
</tbody>
</table>

The investment takes a timeline of three years, $3,379,733 per year.

The mortgage will be approximate the 30% of the total investment, it will be $3,041,760 returned in a period of seven years (from the 4th until the 10th) such that each year the cost of the mortgage is $434,537.

It has been supposed that the percentage of the failures which occur during the guarantee time happen in a 3% of all the sales and each one has an extra cost of $1,000 in average. These costs have been taken into account on the same year which they have been sold.

It has been assumed that the employer’s costs are always the same and it does not depend if the buildings are constructing or producing heat storage items and it does not depend on the production. The number of employers will be 30 and each one has one cost of $30,000 per year.

Finally, it is possible get a financial balance per year with incomes and outcomes, cash flow per year, cumulative cash flow and as a consequence of that analysis, the payback will be known.

Table 8. Cash flow

<table>
<thead>
<tr>
<th>Years</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment</td>
<td>-$3,379,733</td>
<td>-$3,379,733</td>
<td>-$3,379,733</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortgage</td>
<td></td>
<td>-$434,537</td>
<td>-$434,537</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td></td>
<td>-$6,960,000</td>
<td>-$15,312,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guarantee</td>
<td></td>
<td>-$30,000</td>
<td>-$66,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employers</td>
<td>-$900,000</td>
<td>-$900,000</td>
<td>-$900,000</td>
<td>-$900,000</td>
<td>-$900,000</td>
</tr>
<tr>
<td>Incomes</td>
<td>$8,999,000</td>
<td>$19,797,800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash flow</td>
<td>-$4,279,733</td>
<td>-$4,279,733</td>
<td>-$4,279,733</td>
<td>$1,109,000</td>
<td>$3,519,800</td>
</tr>
<tr>
<td>Cumulative cash flow</td>
<td>-$4,279,733</td>
<td>-$8,559,466</td>
<td>-$12,839,199</td>
<td>-$11,730,199</td>
<td>-$8,210,399</td>
</tr>
<tr>
<td>Years</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>-------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Investment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortgage</td>
<td>-$434.537</td>
<td>-$434.537</td>
<td>-$434.537</td>
<td>-$434.537</td>
<td>-$434.537</td>
</tr>
<tr>
<td>Production</td>
<td>-$25.056.000</td>
<td>-$33.408.000</td>
<td>-$26.448.000</td>
<td>-$19.488.000</td>
<td>-$12.528.000</td>
</tr>
<tr>
<td>Guarantee</td>
<td>-$108.000</td>
<td>-$144.000</td>
<td>-$114.000</td>
<td>-$84.000</td>
<td>-$54.000</td>
</tr>
<tr>
<td>Employers</td>
<td>-$900.000</td>
<td>-$900.000</td>
<td>-$900.000</td>
<td>-$900.000</td>
<td>-$900.000</td>
</tr>
<tr>
<td>Incomes</td>
<td>$32.396.400</td>
<td>$43.195.200</td>
<td>$34.196.200</td>
<td>$25.197.200</td>
<td>$16.198.200</td>
</tr>
<tr>
<td><strong>Cash flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative cash flow</td>
<td>-$1.877.999</td>
<td>$6.865.201</td>
<td>$13.599.401</td>
<td>$18.324.601</td>
<td>$21.040.801</td>
</tr>
</tbody>
</table>

The payback is in the 7th year and the profits after 10 years will be $21M.

![Figure 6 Overview of the cash flow](image-url)
6. Conclusions

From the theoretical side of the designing part can be concluded that it is possible to store “waste heat” for use later on, while it otherwise would be lost. So it helps to make a building more energy efficient and eco-friendly.

But from the practical side can be said, that the device is enormous and maybe impractical. So to have here a positive or negative conclusion about, the possible end users should be asked. But strictly space like, there can be concluded that it will fit in every building.

And end user wise, could be concluded that to have only a heat storage and exchanging device to provide hot tap water isn’t preferable. Because of the limited production of hot tap water.

Economically, the project is viable with a high investment for the first three years. After this period, the business generate profits each year until recover the initial investment at the 7th year and then, ten years after to start with the project, the profits arrives at $21M.

To make this project viable after 10 years, it will require new technologies and new ideas to transform and improve the heat storage to be able to attract new users.
Reference

1) http://techon.nikkeibp.co.jp/english/NEWS_EN/20111223/202951/?P=1, visited [26-3-14]


3) http://www.myriadmetals.co.uk/?page_id=145, visited [26-3-14] (Is the reference for weight of metal)

4) http://www.worldsteelprices.com/ (Price of stainless steel)


6) http://www.sigmaaldrich.com/MSDS/MSDS/PrintMSDSAAction.do?name=msdpdf_140385095305142, visited [26-3-14](Source of appendix B)

Appendix A

PRODUCT DATA SHEET

316/316L STAINLESS STEEL
UNS S31600 AND UNS S31603

Type 316 is an austenitic chromium-nickel stainless steel containing molybdenum. This addition increases general corrosion resistance, improves resistance to pitting from chloride ion solutions, and provides increased strength at elevated temperatures. Properties are similar to those of Type 304 except that this alloy is somewhat stronger at elevated temperatures. Corrosion resistance is improved, particularly against sulfuric, hydrochloric, acetic, formic and tartaric acids; acid sulfates and alkaline chlorides.

Type 316L is an extra-low carbon version of Type 316 that minimizes harmful carbide precipitation due to welding.

Typical uses include exhaust manifolds, furnace parts, heat exchangers, jet engine parts, pharmaceutical and photographic equipment, valve and pump trim, chemical equipment, digesters, tanks, evaporators, pulp, paper and textile processing equipment, parts exposed to marine atmospheres and tubing. Type 316L is used extensively for weldments where its immunity to carbide precipitation due to welding assures optimum corrosion resistance.

COMPOSITION

<table>
<thead>
<tr>
<th></th>
<th>Type 316</th>
<th>Type 316L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.08 max.</td>
<td>0.03 max.</td>
</tr>
<tr>
<td>Manganese</td>
<td>2.00 max.</td>
<td>2.00 max.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.045 max.</td>
<td>0.045 max.</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.03 max.</td>
<td>0.03 max.</td>
</tr>
<tr>
<td>Chromium</td>
<td>16.00 - 18.00</td>
<td>16.00 - 18.00</td>
</tr>
<tr>
<td>Nickel</td>
<td>10.00 - 14.00</td>
<td>10.00 - 14.00</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>2.00 - 3.00</td>
<td>2.00 - 3.00</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.10 max.</td>
<td>0.10 max.</td>
</tr>
<tr>
<td>Iron</td>
<td>Balance</td>
<td>Balance</td>
</tr>
</tbody>
</table>

AVAILABLE FORMS

AK Steel produces Types 316 and 316L Stainless Steels in thicknesses from 0.01" to 0.25" (0.25 to 6.35 mm) max. and widths up to 48" (1219 mm). For other thicknesses and widths, inquire.

MECHANICAL PROPERTIES

Typical Room Temperature Properties

<table>
<thead>
<tr>
<th></th>
<th>Type 316</th>
<th>Type 316L</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTS</td>
<td>82 (576)</td>
<td>81 (558)</td>
</tr>
<tr>
<td>0.2% YS</td>
<td>42 (286)</td>
<td>42 (286)</td>
</tr>
<tr>
<td>Elongation</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>% in 2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>H78</td>
<td>H79</td>
</tr>
<tr>
<td>Rockwell</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

316/316L-5-08-01-07
AK STEEL

316/316L STAINLESS STEEL DATA SHEET

SPECIFICATIONS
Types 316 and 316L Stainless Steel sheet and strip are covered by the following specifications:

Type 316  Type 316L
AMS 5524  AMS 5507
ASTM A 240  ASTM A 240
ASTM A 666  ASTM A 666

PHYSICAL PROPERTIES
Density, 0.28 lb/ft³  7.89 g/cm³
Electrical Resistivity, microhm-in (microhm-cm) 68°F (20°C) — 20.4 (74)
Specific Heat, BTU/lb°F (kJ/kg • K) 32 – 212°F (0–100°C) — 0.12 (0.50)
Thermal Conductivity, BTU/hr/ft²°F/W/m • K at 212°F (100°C) — 9.4 (18.2)
at 932°F (500°C) — 12.4 (21.4)
Module of Elasticity, ksi (MPa) 28.0 x 10³ (193 x 10³) in tension
11.2 x 10³ (77 x 10³) in torsion
Mean Coefficient of Thermal Expansion, in/in°F (µm/m • K) 32 – 212°F (0 – 100°C) — 8.9 x 10⁻⁶ (16.0)
32 – 600°F (315°C) — 9.0 x 10⁻⁶ (16.2)
32 – 1000°F (538°C) — 8.7 x 10⁻⁶ (17.5)
32 – 1200°F (649°C) — 10.3 x 10⁻⁶ (18.5)
32 – 1500°F (815°C) — 11.1 x 10⁻⁶ (19.9)
Magnetic Permeability, H = 200
Gersted, Annealed — 1.02 max.
Melting Range, °F (°C) — 2500 – 2550 (1371 – 1399)

CORROSION RESISTANCE
Types 316 and 316L Stainless Steels exhibit better corrosion resistance than Type 304. They provide excellent pitting resistance and good resistance to most chemicals involved in the paper, textile and photographic industries.

HEAT TREATMENTS
Types 316 and 316L are not hardenable by heat treatment.
Annealing: Heat to 1900 – 2100°F (1038 – 1149°C), then rapidly quench.

FORMABILITY
Types 316 and 316L can be readily formed and drawn.

WELDABILITY
The austenitic class of stainless steels is generally considered to be weldable by the common fusion and resistance techniques. Special consideration is required to avoid weld "hot cracking" by ensuring formation of ferrite in the weld deposit. These particular alloys are generally considered to have poorer weldability than Types 304 and 304L. A major difference is the higher nickel content for these alloys which requires slower arc welding speed and more care to avoid hot cracking. When a weld filler is needed, AWS E/ER 316L and 18-8-2 are most often specified. Types 316 and its low-carbon "L" version are well known in reference literature and more information can be obtained in this way.

METRIC CONVERSION
Data in this publication are presented in U.S. customary units. Approximate metric equivalents may be obtained by performing the following calculations:

Length (inches to millimeters) — Multiply by 25.4
Strength (ksi to megapascals or meganewtons per square meter) — Multiply by 6.8948

The information and data in this product data sheet are accurate to the best of our knowledge and belief, but are intended for general information only. Applications suggested for the materials are descriptive only to help readers with their own evaluations and decisions, and are neither guarantees nor to be construed as express or implied warranties of suitability for these or other applications.

Data relating to mechanical properties and chemical analyses are the result of tests performed on samples obtained from specific locations with prescribed sampling procedures; any warranty thereof is limited to the values obtained at such locations and by such procedures. There is no warranty with regard to values of the materials at other locations. AK Steel and the AK Steel logo are registered trademarks of AK Steel Corporation.
Appendix B

1. IDENTIFICATIE VAN DE STOF OF HET MENGSEL EN VAN DE VENNOOTSCHAP/ONDERNEMING

1.1 Productidentificaties
Productbenaming : Barium hydroxide octahydrate

Productnummer : B2507
Leverancier : Sigma-Aldrich
CAS-Nr. : 12230-71-6

1.2 Relevant geïdentificeerd gebruik van de stof of het mengsel en ontraden gebruik
Geïdentificeerd gebruik : Laboratoriumchemikalien, Vervaardiging van stoffen

1.3 Details betreffende de verstrekker van het veiligheidsinformatieblad
Firma : Sigma-Aldrich Chemie BV
Stationsplein 4
3331 LL ZWIJNDRECHT
NETHERLANDS
Telefoon : +31 78-620-5411
Fax : +31 78-620-5421
E-mailadres : eunetechserv@siai.com

1.4 Telefoonnummer voor noodgevallen
Noodtelefoonnummer : 112

2. IDENTIFICATIE VAN DE GEVAREN

2.1 Indeling van de stof of het mengsel
Classificatie volgens richtlijn (EC) Nr 1272/2008 [EU-GHS/CLP]
Acute toxiciteit, Inademing (Categorie 4)
Acute toxiciteit, Orale (Categorie 4)
Huidcorrosie/-irritatie (Categorie 1B)

Classificatie volgens EU-Richtlijnen 67/548/EEG of 1999/45/EG
Schadelijk bij inademing en opname door de mond. Veroorzaakt brandwonden.

2.2 Onderdelen label
Etikettering volgens richtlijn (EC) Nr 1272/2008 [CLP]
Pictogram

Signaalwoord Gevaar
Gevarenwaarschuwingscode (H-code)
H302 Schadelijk bij inslikken.
H314 Veroorzaakt ernstige brandwonden en oogletsel.
H332 Schadelijk bij inademing.
Preventieve code (P-code)
P280 Beschermende handschoenen/ beschermende kleding/ oogbescherming/ gelaatsbescherming dragen.
P305 + P351 + P338 BIJ CONTACT MET DE OGEN: voorzichtig afspoelen met water gedurende een aantal minuten; contactlenzen verwijderen, indien mogelijk; blijven spoelen.
P310 Onmiddellijk een ANTI-GIFCENTRUM of een arts raadplegen.
Aanvullende gevarenaanduidingen

Volgens Europese Richtlijn 67/548/EEG zoals geamendeerd.
Gevarensymbolen

R-zin(nen)
R34 Veroorzaakt brandwonden.
R20/21 Schadelijk bij inademing en bij aanraking met de huid.
S-zin(nen)
S26 Bij aanraking met de ogen onmiddellijk met overvloedig water afspoelen en deskundig medisch advies inwinnen.
S36/37/39 Draag geschikte beschermende kleding, handschoenen en een beschermingsmiddel voor de ogen/het gezicht.
S45 Bij een ongeval of indien men zich onwel voelt, onmiddellijk een arts raadplegen (indien mogelijk hem dit etiket tonen).

2.3 Andere gevaren - geen

3. SAMENSTELLING EN INFORMATIE OVER DE BESTANDDELEN

3.1 Stoffen
Formule : \( \text{H}_2\text{BaO}_2 \cdot \text{8H}_2\text{O} \)
Moleculair gewicht : 315,46 g/mol

<table>
<thead>
<tr>
<th>Bestanddeel</th>
<th>Concentratie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium hydroxide</td>
<td></td>
</tr>
<tr>
<td>CAS-Nr.</td>
<td>12230-71-8</td>
</tr>
<tr>
<td>EG-Nr.</td>
<td>241-234-5</td>
</tr>
</tbody>
</table>

4. EERSTEHULPMAATREGELEN

4.1 Beschrijving van de eerstehulpmaatregelen

Algemeen advies
Een arts raadplegen. Dit veiligheidsinformatieblad aan de dienstdoende arts tonen.

Bij inademing
Bij inademing het slachtoffer in de frisse lucht brengen. Als de ademhaling is gestopt kunstmatig beademing. Een arts raadplegen.

Bij aanraking met de huid
Verontreinigde kleding en schoenen onmiddellijk uittrekken. Afwassen met zeep en veel water. Een arts raadplegen.

Bij aanraking met de ogen
Grondig met veel water spoelen gedurende tenminste 15 minuten en een arts raadplegen.

Bij inslikken

4.2 Belangrijkste acute en uitgestelde symptomen en effecten
De stof veroorzaakt ernstige beschadiging van het weefsel van slijmvlies en bovenste ademhalingswegen, ogen en huid, Hoesten, Kortademigheid, Hoofdpijn, Misselijkheid

4.3 Vermeiding van de vereiste onmiddellijke medische verzorging en speciale behandeling
geen gegevens beschikbaar
5. **BRANDBESTRIJDINGSMAATREGELEN**

5.1 Blusmiddelen
   - Geschikte blusmiddelen
     Gebruik waternevel, alcoholbestendig schuim, droogpoeder, of kooldioxide.

5.2 Speciale gevaren die door de stof of het mengsel worden veroorzaakt
   - Bariumoxide

5.3 Advies voor brandweerlieden
   - Draag indien nodig een persluchtmasker bij brandbestrijding.

5.4 Nadere informatie
   - geen gegevens beschikbaar

6. **MAATREGELEN BIJ HET ACCIDENTEEL VRIJKOMEN VAN DE STOF OF HET MENGSEL**

6.1 Persoonlijke voorzorgsmaatregelen, beschermde uitrusting en noodprocedures

6.2 Milieuvoorzorgsmaatregelen
   - Product niet in de rioleringslaten komen.

6.3 Insulaties- en reinigingsmethoden en -materiaal

6.4 Verwijzing naar andere rubrieken
   - Voor afvalverwijdering zie sectie 13.

7. **HANTERING EN OPSLAG**

7.1 Voorzorgsmaatregelen voor het veilig hanteren van de stof of het mengsel

7.2 Voorwaarden voor een veilige opslag, met inbegrip van incompatibele producten

7.3 Specifiek eindgebruik
   - geen gegevens beschikbaar

8. **MAATREGELEN TER BEHEERSING VAN BLOOTSTELLING/PERSOONLIJKE BESCHERMING**

8.1 Controleparameters
   - Bestanddelen met grenswaarden voor de werkplek
     | Bestanddeel | CAS-Nr. | Waarde | Controleparameters | Basis |
     |-------------|---------|--------|--------------------|-------|

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TWA | 0,5 mg/m³ | Wijziging Arbeidsomstandigheden - Wettelijke grenswaarden

Opmerkingen | bestuurlijke grenswaarde

| TWA | 0,5 mg/m³ | Indicatieve grenswaarden voor beroepsmatige blootstelling

Indicatieve

| TGG-8 uur | 0,5 mg/m³ | Wijziging Arbeidsomstandigheden - Wettelijke grenswaarden

Indicatieve

| TWA | 0,5 mg/m³ | Indicatieve grenswaarden voor beroepsmatige blootstelling

Indicatieve

| TWA | 0,5 mg/m³ | Indicatieve grenswaarden voor beroepsmatige blootstelling

Indicatieve

8.2 Maatregelen ter beheersing van blootstelling

Passende technische maatregelen

Gebruiken volgens goede industriële hygiëne en veiligheid. Handen wassen voor elke werkenbrakking en aan het einde van de werkdag.

Persoonlijke beschermingsmiddelen

Bescherming van de ogen / het gezicht

Gezichtsbescherming en veiligheidsbril Gebruik gezichts- en/of oogbescherming getest en goedgekeurd door officiële instellingen zoals NIOSH (US) of EN166 (EU).

Bescherming van de huid


De gekozen beschermhandschoenen moeten voldoen aan de specificaties van EU-Richtlijn 89/686/EEG en de norm En 374, die daarvan is afgeleid.

Bescherming via onderdoppling

Materiaal: Nitrilrubber
Minimale laag dikte: 0,11 mm
Penetratietijd: > 480 min
Getest materiaal:Dermatril® (Aldrich Z677272, Maat M)

Bescherming met waterstraal

Materiaal: Nitrilrubber
Minimale laag dikte: 0,11 mm
Penetratietijd: > 30 min

Sigma-Addrich - B2507  Pagina 4 van 8
Getest materiaal: Dermatril® (Aldrich Z577272, Maat M)
bron data: KCL GmbH, D-36124 Eichenzell, Telefoon +49 (0)6659 873000, e-mail sales@kcl.de,
test methode: EN374
Bij gebruik in oplossing, of gemengd met andere bestanddelen, of onder omstandigheden anders
dan volgens EN 374, eerst contact opnemen met de leverancier van de volgens de EG-richtlijnen
goedgekeurde handschoenen. Deze aanbeveling is ter info en moet door de Veiligheidsmanager
worden beoordeeld per situatie. Het moet niet gezien worden als directe toestemming voor ieder
specifieke gebruiksscenario.

Lichaamsbescherming
Volledig pak voor bescherming tegen chemicaliën, het type beschermingsmiddelen is afhankelijk
van de concentratie en hoeveelheid gevaarlijke stoffen op de betreffende werkplek.

Bescherming van de ademhalingswegen
Waar ademhaling risico’s zich voordoen, gebruik indien nodig een luchtdzuiverende gelaatmasker.
Als bescherming tegen deze belastende niveaus, gebruik type N100 (US) of type P3 (EN 143)
gelaatmasker. Als het gelaatmasker het enige middel van bescherming is, gebruik een volledig-
gezicht ademhalingsmasker (zuurstofmasker). Gebruik ademhalingsmaskers getest en
goedgekeurd door officiële overheidsinstanties zoals NIOSH (US) of CEN (EU).

9. FYSISCH EN CHEMISCHE EIGENSCHAPPEN

9.1 Informatie over fysische en chemische basiseigenschappen
a) Voorkomen Vorm: vast
b) Geur geen gegevens beschikbaar
c) Geurdrempelwaarde geen gegevens beschikbaar
d) pH 12,5 bij 50 g/l bij 20 °C
e) Smelt-/vriespunt Smeltpunt-traject: 78 °C - lit.
f) Beginkookpunt en kooktraject geen gegevens beschikbaar
g) Vlampunt niet van toepassing
h) Verdampingssnelheid geen gegevens beschikbaar
i) Ontvlambaarheid (vast, gas) geen gegevens beschikbaar
j) Hoge/lage ontvlambaarheid of ontplofingsgrenswaarden geen gegevens beschikbaar
k) Dampspanning geen gegevens beschikbaar
l) Dampdichtheid geen gegevens beschikbaar
m) Relatieve dichtheid 2,180 g/cm³
n) Oplosbaarheid in water oplosbaar
o) Verdelingscoëfficiënt n-octanol/water geen gegevens beschikbaar
p) Zelfontbrandingstemperatuur geen gegevens beschikbaar
q) Ontledingstemperatuur geen gegevens beschikbaar
r) Viscositeit geen gegevens beschikbaar
s) Ontploffingseigenschappen geen gegevens beschikbaar
t) Oxiderende eigenschappen geen gegevens beschikbaar

9.2 Andere veiligheidsinformatie
Bulk soortelijk gewicht 0,90 - 1,1 g/l
10. STABILITEIT EN REACTIVITEIT

10.1 Reactiviteit
geen gegevens beschikbaar

10.2 Chemische stabiliteit
geen gegevens beschikbaar

10.3 Mogelijke gevaarlijke reacties
geen gegevens beschikbaar

10.4 Te vermijden omstandigheden
geen gegevens beschikbaar

10.5 Chemisch op elkaar inwerkende materialen
zuren

10.6 Gevaarlijke ontlingsproducten
Andere ontlingsproducten - geen gegevens beschikbaar

11. TOXICOLOGISCHE INFORMATIE

11.1 Informatie over toxicologische effecten

Acute toxiciteit
LD50 Oraal - rat - 550 mg/kg

Huidcorrosie/-irritatie
geen gegevens beschikbaar

Ernstig oogletsel/oogirritatie
geen gegevens beschikbaar

Sensibilisatie van de luchtwegen/de huid
geen gegevens beschikbaar

Mutageniteit in geslachtscellen
geen gegevens beschikbaar

Kankerwekkendheid
IARC: Geen bestanddeel van dit product, voorzover aanwezig in een concentratie van meer dan of
gelijk aan 0.1% is geïdentificeerd als een waarschijnlijk, mogelijk of bevestigd carcinogeen
door IARC.

Giftigheid voor de voortplanting
geen gegevens beschikbaar

Specifieke doelorgaanotoxiciteit - eenmalige blootstelling
geen gegevens beschikbaar

Specifieke doelorgaanoxiciteit - herhaalde blootstelling
geen gegevens beschikbaar

Gevaar bij inademing
geen gegevens beschikbaar

Mogelijke gezondheidsaandoeningen

Inademing Schadelijk bij inademing. De stof is uiterst destructief voor het weefsel van
de slijmvlies en de bovenste ademhalingswegen.

Inname Schadelijk bij opname door de mond. Veroorzaakt brandwonden.

Huid Kan schadelijk zijn bij absorptie door de huid. Veroorzaakt brandwonden
aan de huid.

Ogen Veroorzaakt brandwonden aan de ogen.

Tekenen en Symptomen van Blootstelling
De stof veroorzaakt ernstige beschadiging van het weefsel van slijmvlies en bovenste
ademhalingswegen, ogen en huid., Hoesten, Kortademigheid, Hoofdpijn, Misselijkheid

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Additionele Informatie
RTECS: geen gegevens beschikbaar

12. ECOLOGISCHE INFORMATIE
12.1 Toxiciteit
geen gegevens beschikbaar
12.2 Persistentie en afbreekbaarheid
geen gegevens beschikbaar
12.3 Bioaccumulatie
geen gegevens beschikbaar
12.4 Mobiliteit in de bodem
geen gegevens beschikbaar
12.5 Resultaten van PBT- en zPzB-beoordeling
geen gegevens beschikbaar
12.6 Andere schadelijke effecten
geen gegevens beschikbaar

13. INSTRUCTIES VOOR VERWIJDERING
13.1 Afvalverwerkingsmethoden
Product
Restanten en niet-herbruikbare oplossingen aanbieden aan een vergunninghoudend verwijderingsbedrijf. De stof oplossen of vermengen met een brandbaar oplosmiddel en verbranden in een chemische verbrandingsinstallatie voorzien van nabranders en gaswasser.
Verontreinigde verpakking
Verwijderen als ongebruikt product.

14. INFORMATIE MET BETREKKING TOT HET VERVOER
14.1 UN nummer
ADR/RID: 3262  IMDG: 3262  IATA: 3262
14.2 Juiste ladingnaam overeenkomstig de modelreglementen van de VN
ADR/RID: BIJNDE BASISCHE ANORGANISCHE VASTE STOF, N.E.G. (Barium hydroxide)
IMDG: CORROSIVE SOLID, BASIC, INORGANIC, N.O.S. (Barium hydroxide)
IATA: Corrosive solid, basic, inorganic, n.o.s. (Barium hydroxide)
14.3 Transportgevaarklasse(n)
ADR/RID: 8  IMDG: 8  IATA: 8
14.4 Verpakkingsgroep
ADR/RID: II  IMDG: II  IATA: II
14.5 Milieugevaren
ADR/RID: nce  IMDG Marine pollutant: no  IATA: no
14.6 Bijzondere voorzorgen voor de gebruiker
geen gegevens beschikbaar

15. REGELGEVING
Dit veiligheidsinformatieblad voldoet aan de eisen van Verordening (EG) Nummer 1907/2006.
15.1 Specifieke veiligheids-, gezondheids- en milieureglementen en -wetgeving voor de stof of het mengsel
geen gegevens beschikbaar
15.2 Chemischeveiligheidsbeoordeling
geen gegevens beschikbaar
16. **OVERIGE INFORMATIE**

**Nadere informatie**
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Provide LNG Vehicles

Originating Requirements Document

Lars Kloekke, Tarek Eissa & Sergi Bernà

June 2014
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Chapter 0: Introduction

0.1 Problem to be solved

The main problem of LNG transportation is maintaining natural gas in liquid state and reuses the part which could not be maintained into LNG.

The transportation of LNG is done by LNG carriers (ships) but also by trains or trucks. Pipelines are a method of transporting LNG in a continuous fashion. LNG is transported at atmospheric pressure and at approximately -162 °C, at which point the natural gas condenses to liquid. This low temperature requires special storage and transport conditions. Pipelines will be less effective for the transport of small amounts LNG for these reasons. However, it might be possible to develop some sort of modular system incorporating train, trucks and small ships for efficient transport across different vehicle types. The system requires a universal storage unit allowing for fast and easy switch to a different mode of transport without pumping the LNG. Each time LNG has to be pumped from tank to tank, pumping energy is transferred into heat, causing the LNG to rise in temperature resulting in more boil-off gas. For large ships, with a capacity exceeding 100,000 cubic meters, a modular storage units will be less effective as numerous of these units must be placed aboard. Each modular unit is best conformed to a truck. Since trailer manufacturers already are delivering trailers capable of transporting LNG, some aspects of these trailers might be used in the development of the storage unit.

0.2 Potential solutions

As a possible solution for transporting LNG, we primarily focus on the transport capacity of these vehicles and pipelines. When insulating the storage tank or pipeline, the efficiency of insulation is not 100% (3). Therefore, during the transportation the temperature fluctuates around -162 °C, and some LNG is converted to gas, losing in that way a few percentage of all LNG transported. A cooling mechanism must be incorporated in order to maintain the temperature within the tank. We propose a liquid nitrogen system which can be pumped around the storage tank or pressurized nitrogen which can be depressurize alongside the tank, reducing the temperature like a refrigerator through gas expansion. The LNG that has been converted into gas can be used to drive engine of the vehicle regardless of whether it is a sea vessel, a train or a truck. The vehicles which transport LNG can run with gas (providing of that LNG), with conventional fuels or with a mixed engine combining gas and conventional
fuels as current LNG carriers. The vehicles that run on LNG have specially three parts with huge differences to current vehicles on the engine, fuel tank and the devices to refuelling.

The fuel tank has to be very well insulated in order not to convert all liquid to gas into the tank; in that case the pressure will be really high damaging the tank. LNG engines have 30% more efficient than conventional engine models implying greater autonomy and 20% less emissions. The transportation vehicles have been divided into four groups: Large ships, small ships, trains, and trucks.

**Large Ships**

For the transportation of large amounts of LNG from its recovery location to its proposed market, it has to travel a large distance. Pipelines do not have the efficiency a large ship can provide in this situation concerning insulation properties, especially over these long distances. Each ship is capable of carrying about 130,000 cubic metres of LNG and is thoroughly insulated to prevent excessive loss of LNG (4). It is possible to use any boil-off of LNG to power these vessels. We propose 10 vessels over the next three years in order to provide enough LNG, each costing 250 million euros.

**Pipelines**

Pipelines can be used for the continuous transportation of liquid and gasses over large distances across land and water. Since pipelines are fixed and require large expensive pumping mechanisms to displace the fluid, they are only viable for large amount of LNG which is required to be transported regularly over a certain distance. The capacity and length of a pipeline depends on the required demand in a certain area. This also influences the cost of a pipeline which can vary greatly between distances.

**Small Ships**

For the transportation of LNG over land, rivers can be used via small ships. These ships are able to transport storage tanks of LNG perhaps through a modular design also applicable on trains and trucks. The desire is to find a storage medium for LNG which is similar to the modularity of cargo containers. These smaller ships have limited cargo capacity, estimated around 10,000 cubic meters of LNG. The system requires around 50 over the next three years, each costing around 10 million euros.

**Trains**

Like the small ships, trains can be used to transport modular storage units of LNG across land. Depending on the length of the train, the carrying capacity can vary easily to dose the amount of LNG transported. The system will require at least four trains for the next three years.

**Trucks**

Similarly to the trains and small ships, trucks must be capable of transporting a, preferably singular, modular storage unit of LNG. Trucks can be used for fast and custom transportation of LNG to a desired location. Although the trucks are relatively small, they are perfect transport media towards the end-
consumer. All of these vehicle types have to work in unison in order to supply LNG efficiently and cost-effective.

0.3 Stakeholders

The stakeholders have been identified following the supply chain of LNG to reach customers.

Figure 3. Supply chain of LNG (http://www.altenesol.com)

The following section describes the stakeholders regarding the LNG vehicles and transportation.

There are three main stakeholders:

- Transportation Companies using LNG as a fuel within their network. By cooperating with the Synchro-modal LNG network, optimization might be achieved through the improvement of efficiency and fuel cost especially, with increased demand of LNG (5).
- Oil and Gas Recovery Companies which can operate in a new large market.
- Vehicle/Engine Manufacturers will be providing the tools and equipment necessary for transporting LNG to the consumer and the operating of vehicles on LNG especially, if the demand for LNG rises and if there will be a transition to the intensive use of LNG.
Other stakeholders, with perhaps a smaller influence on the system:

- The transportation personnel required for the transport of LNG from the recovery well to the consumer.
- Insurers and investors in the transportation market.
- Communities and the environment, which should experience less pollution.
- Governments, which may contribute to the development of the infrastructure for the transportation of LNG by new government policies and incentives.
- Consumers, the consumers need vehicles which are suitable for the usage of LNG.

0.4 High Level System Goals

The system’s main goal is to transport LNG from the recovery location towards the consumer using safe and efficient transportation techniques. The transportation of LNG by train, truck, ship and pipeline requires an engineering approach as the storage conditions of LNG are rather extreme when compared to most fuels used by society. Cooling mechanisms in combination with insulated pressure tanks are required, the size and properties of which depends on the mode of transportation. The transportation vehicles driving on LNG need storage units to replace their normal petrol tanks, of which the design can be based upon transportation vehicles. Furthermore, a regasification system must be incorporated within engines of consumer vehicles in order for vehicles to use LNG as a fuel. In terms of sales of the transportation vehicles, presently the consumer is given a choice when ordering a vehicle. The choice now exists between petrol, diesel, and natural gas engines along with other implications of the choice of fuel. The introduction of LNG vehicles is simply introduced as a fourth option. The sales of LNG powered vehicles might be encouraged through additional benefits now only available for hybrid and electric vehicles. The long term goal is to transport LNG safely and securely using various types of vehicles depending on location and distance to be travelled.
Chapter 1: System Overview

1.1 Project scope

There are two different ways to work on providing LNG vehicles. The first are the vehicles designated to transport LNG to and from transport hubs and then there are the vehicles that actually run on LNG fuel. Naturally, a combination can be made of both. The vehicles that run on LNG fuel are similar to existing vehicle but involve of course some differences in the engine technology and fuel tanks. These new vehicles must be designed and manufactured and placed in the market. However this high concept will be focused on the vehicles that can transport the LNG itself. These vehicles must be available for the LNG infrastructure.

1.2 Advantages of LNG

The advantages of Liquefied Natural Gas are that its high energy content, the total amount of energy needed is reduced. It expands 600 times to reach its gaseous state (1 unit of LNG = 600 units of natural gas). A large amount of natural gas can be stored and transported at low pressure. Finally it is a clean fuel; it contributes to improved product quality and reduces maintenance costs.

1.3 Scenarios

Liquefied Natural Gas (LNG) is a new form of primary fuel and can be used for the powering of any motorized vehicle. As natural gas becomes more desirable for transportation, technology providers have eased its adoption by devising new engines and retrofits for cars, trucks, and ships (1). Liquefied Natural Gas (LNG) forecasts are highly-structured and capital intensive in order to protect the investment return that projects developers conventionally covered all their future LNG. The past years have witnessed a dramatic development in LNG industry which is under metaphases from an infant towards a maturing industry with the on-going process of slackening in the world market, LNG plays an increasingly important role in meeting the rapid gas demand worldwide by offering its merits of diversification and flexibility for securing gas supply of price signals cross isolated regions. According to BP 2010; “So far, LNG accounts for 30.5% of world trade volume and the figure is expected to be growing” (2).
Figure 5. Scenario: Maintenance
Figure 6. Scenario: Pick-up
Figure 7. Safety Scenario
Figure 8. Design Scenario
1.4 Boundaries and External System

The external system of Provide Transport Means is modelled in the following structure where vehicle manufacturing, maintenance and supplier services have an important role. All of this is managed by logistic centre and restricted by the government.

Figure 9. External system hierarchy
The functional IDEF0 of the external system is showed in the following figure:

Figure 10. External system IDEF0

In this project, the main function is Provide Transport Mean. All inputs, outputs, controls and mechanisms of this system are showed below:
Figure 11. I/O/C/Ms of the main function A.3.2. Provide transport means
### 1.4.1 Items Flow Dictionary

**Controls**

<table>
<thead>
<tr>
<th>Goals</th>
<th>Provide engineering designs which are technically feasible of transportation techniques for LNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Info Subsidies</td>
<td>Know the available budget to invest in our business and know where this budget comes</td>
</tr>
<tr>
<td>Quality Goals</td>
<td>Criteria for achieving a certain quality level conforming to safety standards, standard measurements and safety regulation posed by governments. Each vehicle must be thoroughly tested by quality controllers in order to verify their quality elements</td>
</tr>
<tr>
<td>Safety Regulations</td>
<td>Regulation posed by governments and other organizations to ensure safe transport of LNG</td>
</tr>
</tbody>
</table>

**Supply & Demand Factors**

| Indication or prediction of the anticipated level of supply and demand. This can be used to determine the number of vehicles to produce, as well as the type of vehicle required for the transport of LNG to a certain location |

**Vehicle Restrictions**

Rules posed by vehicle manufacturers during the design steps of the transport vehicles

**Inputs**

<table>
<thead>
<tr>
<th>Power</th>
<th>Energy used for the production of LNG transportation components as well as several auxiliary functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td>Primary source for the production of LNG transportation components. These raw materials are converted into the required components for the development of the engines, regasification systems etc.</td>
</tr>
</tbody>
</table>
### Controls

- **Engineering Subsystem**: Engineers working on maximizing profit through process optimization.
- **Logistics Subsystem**: Logistic activities performed by the Logistics system.
- **Supervisors**: Controller who checks if products conform to government regulations.
- **Vehicle Manufacturers & Designers**: Manufacturers of transportation vehicles and provide advice on vehicle design.
- **Warehouse**: Location for equipment or part storage.

### Outputs

- **Vehicles specifications**: Exact information on the physical dimensions, materials, and quality of the vehicles. Certain vehicle components are produced within our system and have to comply to the vehicle and docking restrictions posed by external systems.
- **Transport modes**: Distinguishes between different ways to perform transport.
- **Module specifications**: Exact information on the physical dimensions, materials, and quality of the storage modules. The storage modules are produced within our system and have to comply to the vehicle and docking restrictions posed by external systems.
- **Products sold**: Products include all the different modes of transportation to the transportation companies. This includes pipelines and all the systems which makes the different between current vehicles and LNG vehicles as regasification system, engines and LNG tanks for every kind of vehicles (trucks, trains, barges, and ships).
1.5 Operational Objectives Hierarchy

In the next diagram is showed the importance of the Operational Objectives.

Figure 4. Objectives hierarchy
Chapter 2: Designers, Process & Documentation

2.1. Designers

The design team will consist of team members with expertise in the field of designing and those who are experienced in implementing new technologies, providing companies solutions for problems they encounter. Especially problems related with designing, new technologies. It is also necessary that every team member has feeling for transportation and design. The main purpose of the team is to use safe and efficient transportation techniques to transport LNG from the recovery location towards the consumer.

2.2. Process

Achieving the aims of this project demands a lot of processes that will be defined later on in this report. Creating the functional architecture is one of the most important steps in this process, as the system boundaries can be matched with the triad and super triad teams. Then, all the inputs and outputs are determined for this system. Every function that is identified in the functional architecture and their resources will be explained in the stakeholder's requirements document. Then, the physical architecture and in the end the goal, a system for the safe and efficient transportation techniques needs to be delivered. Finally, this system will be implemented in the whole system in the super triad.

2.3. Documentation

The final results of this group project will be based on documents. All these documents will be created and delivered:

D1. Thursday 1st of May 2014: First version of the high concept of the system “to be”. The theme of you system will be given to you after the team formation by the teachers immediately after the formation of your team.


D3. Tuesday 27th of May 2014: First attempt to integrate your system within a triad of three systems (two other teams), a two level functional architecture achieved, and physical interfaces with the other systems explored

D4. Tuesday 3rd of June 2014: Final draft of requirements documents, final draft of Functional Architecture, first draft of Physical architecture with interfaces, first draft of Allocated Architecture. Final draft of the triad integration, first attempt of integration of the super-triad.

Final project document (due Friday the 20th of June) and pitch presentations (pre-planned for 24-26 June). The final form of the assignment is a project document. The system will be defended by the team, in front of the other teams in the triad and super-triad, and also the instructors, who will ask questions
The project document of a team is: a typically 40 page dossier that illustrates the design of the system – organized in the way taught by the book, plus the CORE file containing the requirements and the digital version of the hierarchy of diagrams (functional, physical, and operational).

The stakeholders requirement document (ORD) will be the document that will be used to communicate with the stakeholders with clear illustration of what the experts think that is a necessary outcome of the design in line with the customers can understand what the experts are saying. The SRD will be the document that will be used to communicate with the engineers. The SRD is a digital form will be designed by using the CORE database software. This system design document contains information for the engineers that is important for them to design the system.

2.4. Tools:

The tools that will be used in the project:

CORE 9 program:

This modelling software will be used in order to design the functional and physical model.

Microsoft Visio:

Flows will be made visual by using the Visio software package of Microsoft.
Chapter 3: Requirements

In this section we will provide an overview of objectives and requirements proposed by our stakeholders. These objectives will be incorporated within our design of our system.

The first objective is to design a modular storage unit capable of transporting LNG. These modules can be switched as shipping containers between various modes of transport. For our system, modularity is most efficient between trucks, trains and small barges, considering their transport capacities. For example, it would be possible to transfer a storage module directly from a truck on to a train without pumping the LNG from and to (loss of LNG). For large sea vessels, this becomes more difficult, since their storage capacity is very large. We propose the current system in which large amount of pressurized LNG is stored in ‘bells’ or domes within the vessel. These modules must be safe during transport, thereby withstanding impact and open flames to a certain degree. Also, checklists must be present during the start and end of transport, ensuring a standard safe operating of our drivers.

Furthermore, these storage modules must be insulated and include a cooling mechanism in order to prevent boil-off gas. A maximum percentage of 2% loss of LNG per 1000 km of transport we find reasonable. Any boil-off gas produced during transport must be collected and re-used as an energy source for the transport vehicle by rerouting the gas through the normal gas tank of the vehicle if possible. The capacity of the storage modules must be around 40 m$^3$ of LNG. For the larger sea vessels, the capacity must be around 130,000 m$^3$.

Trucks need a transport range on one fuel tank of at least 250 km based on a standard 400 bhp gas engine. For trains, this range increases to at least 1000 km with 3000 bhp engines, capable a carrying at least 30 cars. Each car contains one storage module. Barges must carry at least 200 storage units over a distance of at least 2000 km. Its engines must be able to deliver at least 1400 kW each (containing two). Larger sea vessels must be able to transfer the LNG over 3000 km, containing two 17000 kW engines for propulsion.

Finally, the requirements of the pipelines almost all depend on the distance to be crossed. The length of the pipelines varies up to 3000 km, however a stable demand at the destination is required. The pump used to displace the fluid depends on the required volumetric flow rate and the distance to be crossed. Friction within the tube caused by bends or wall friction can increase the required power of the pump significantly.
### 3.1. Operational Phase Requirements

#### 3.1.1. Inputs/Outputs (Functional) requirements for operations

<table>
<thead>
<tr>
<th>Functions</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A.3.2 Provide transport means</strong></td>
<td>Provide all kind of vehicles and pipelines specifications</td>
</tr>
<tr>
<td><strong>A.3.2.1 Control all kind of flows</strong></td>
<td>Give baselines to manufacturing process</td>
</tr>
<tr>
<td></td>
<td>Give baselines to ensure quality and meet regulations</td>
</tr>
<tr>
<td></td>
<td>Evaluate costs and fix prices</td>
</tr>
<tr>
<td><strong>A.3.2.2 Design vehicles and pipelines</strong></td>
<td>Provide semi-finished components (re-gasification system, tanks and engines)</td>
</tr>
<tr>
<td></td>
<td>Provide products specifications</td>
</tr>
<tr>
<td></td>
<td>Check production costs</td>
</tr>
<tr>
<td><strong>A.3.2.2.1 Command centre</strong></td>
<td>Provide baselines to produce components as schedules and manufacturing steps.</td>
</tr>
<tr>
<td></td>
<td>Provide blueprints and specifications</td>
</tr>
<tr>
<td></td>
<td>Storing specifications</td>
</tr>
<tr>
<td><strong>A.3.2.2.2 Keep materials on stock</strong></td>
<td>Provide a place to keep raw materials and semi-finished or finished products before to sale</td>
</tr>
<tr>
<td><strong>A.3.2.2.3 Produce and design products</strong></td>
<td>Design components to be produced</td>
</tr>
<tr>
<td></td>
<td>Provide components to sale</td>
</tr>
<tr>
<td><strong>A.3.2.3 Ensure to meet Regulation &amp; Quality</strong></td>
<td>Provide high quality</td>
</tr>
<tr>
<td></td>
<td>Provide safety</td>
</tr>
<tr>
<td></td>
<td>Ensure to meet government and standard regulations</td>
</tr>
<tr>
<td><strong>A.3.2.4 Maximize profits</strong></td>
<td>Get a 20% profit on turnover</td>
</tr>
</tbody>
</table>
Chapter 4: The functional architecture

4.1. The First level Decomposition

The functional architecture of Provide Transport Means is showed above:

![Functional hierarchy of Provide Transport Means (2 levels)](image)

*Figure 5. Functional hierarchy of Provide Transport Means (2 levels)*

The relationship between all of these functions is modelled as it can be seen in the following figure:
Figure 6. IDEF0 of A.3.2. Provide transport means
4.2. The Second Level Decomposition

In this section it will be analysed the second level of our system. The only function with other levels is Design Vehicles and Pipelines. It will be analysed inputs, outputs, controls and mechanisms, its sub functions and the relations between its sub functions.

Figure 15. I/O/C/Ms of the function A.3.2.2. Design vehicles and pipelines
Figure 16. Function hierarchy of A.3.2.2. Design vehicles and pipelines

Figure 17. IDEF0 of A.3.2.2. Design vehicles and pipelines
4.3. Traceability of Requirements

The traceability of requirements is showed in the following figure:

Figure 18. Traceability of requirements hierarchy
And above, the spider diagram:

Figure 19. Spider diagram of requirements
Chapter 5. Triad interaction

A part of this project is also the triad interaction of Provide LNG Structure. Inputs, outputs, controls and mechanisms diagram is illustrated below as well as the 3 groups which integrate this section 3. Provide LNG structure relation.

Figure 20. I/O/C/Ms of triad A.3. Provide LNG Structure
Figure 21. IDEF0 of triad A.3. Provide LNG Structure
5.1. Interfaces within our Triad

Within our triad, we have several interfaces with the other systems. In this section we will provide a short overview how these interfaces look like.

The first interface is the vehicle restrictions posed by the designers of the transport hubs. Our vehicles have to be conformed to these specifications, which mainly include the docking capabilities. The docking of vehicles is the primary physical interaction between our systems and has to be aligned. The designers of the transport hubs do take into account the generic attributes of the different modes of transportation, however the docking capabilities of the vehicles can be designed in various ways. This also includes the incorporation of pipelines which can lie between transport hubs.

The second interface is between us and the designers of the infrastructure of the LNG distribution system. We provide them the various modes of transportation as well as their capabilities. From this information, the designers can choose the appropriate mode of transport between the transport hubs based on customer demand and other variables.
Chapter 6. The physical components

6.1. Physical architecture

6.2 Description Components

Logistics Subsystem:
This physical component includes a portion of the planning and logistics department en operates the entire flow within LNG system. From here, the required demand in a geographical area is determined or forecasted, where after it is ensured the right amount of LNG is transported to a certain destination. These operations can be very cumbersome due to their predictive nature, and therefore operating within this department requires a high skill level. Furthermore, this department monitors the infrastructure as well for availability, efficiency etc.

Warehouse
The warehouse all the base materials used for the production of LNG specific vehicle components such as the regasification systems. This warehouse is located at the nearest production facility for logistical reasons. Furthermore, the warehouse is manned by picking crews delivering the required components based on the demand information acquired from the vehicle manufacturers.

Vehicle Manufacturers
The vehicle manufacturers deliver the actual vehicles to our system. These vehicles include the ships and trains, and therefore these vehicle manufacturers include shipyard and train depots as well as truck manufacturers. A part of their inputs are our design plans for each vehicle.
Supervisors
Supervisors are knowledgeable people who monitor the quality of the transported LNG, and ensure we are conforming to government regulations. This can be done through checklists or other quality controlling methods.

Engineering Subsystem
The engineering subsystem entails the group of engineers responsible for the design plans and the continuous improvement of production processes, vehicles, and components. Their main function is to maximize profits across the entire system, which can be reached through optimization of production processes and transport methods.

6.3 Vehicle Components

Train:
Is a form of rail transport consisting of a series of vehicles propelled along a rail track to transport cargo. Each linked part of a train is called a "car ". The front part of the train is called the locomotive.

Parts:
- Locomotive: the vehicle at the front of a train that pulls it.
- Truck: a railway vehicle used for carrying goods.
- Engine: a vehicle that operate a train.
- Coupler: a device for coupling two railroad cars
- Brakes: A device for slowing or stopping motion, as of a vehicle, especially by contact friction.
- Wheels: A solid disk or a rigid circular ring connected by spokes to a hub, designed to turn around an axle passed through the centre
- Cab : the front part of a train, where the driver sits.
- Bogie: framework carrying wheels, attached to a vehicle.
- Safety systems: driver safety circuits, indicator and display systems, or Doppler radar sensors.
- Storage tanks: tanks that store LNG.
- Fuel tanks: tanks that are provided with fuels to operate the train.
**Pipelines:**
The mechanism that transport LNG through it. Also provide an economical method of transporting fluids over great distance.

Parts:
- Pipes: hollow cylinder or tube used to conduct a liquid, gas.
- Compressor stations: located along the line to move the product through the pipeline.
- Metering stations: measures the flows of Gas along the pipeline.
- Valves: these gateways allow free flow or restriction of gas flow.
- Control, safety stations: monitor and control Gas in pipelines. For example Leak detection systems.

**Barges:**
A large sized boat having a flat bottom and normally it does not have any propelling mechanism of its own.

Parts:
- Wheel houses: The wheelhouse is built above the engine room. It use for providing information on engine and generator.
- Pilot houses: are fabricated for use on ships and barges. For example the full pilot house structure, Ladders and railings.
- Engine room: including fuel tanks, water tanks, ballast tanks and storage tanks.
- Piping systems: are used throughout ships, at shipping terminals and on offshore platforms. For example, vapour piping systems.
- Pump supports and columns: support the pumping through the barges for being safe, efficient.
- Valve assemblies: are used for controlling in barges processes for example, pressure, flow control, metering.
- Ladders, cage ladders and rails: are used for providing facilities for the works on barges.
- Deck enclosures and containers: are used for carrying any goods.
- Louver vents: a kind of physical installation that helps vent air through a fixture that incorporates slanted pieces for natural control in heating and cooling systems.
- Hull: The frame or body of a ship, exclusive of masts, engines, or superstructure.
**Large ships:**

Are generally distinguished from boats based on size, shape and cargo. Ships are used on lakes, seas, and rivers for a variety of activities.

Parts:

- **Hull**: The frame or body of a ship, exclusive of masts, engines, or superstructure.
- **Bridge**: an area at the front of the ship. It is also the room from the ship which can be commanded.
- **Bulbous**: modifies the way the water flows around the hull.
- **Crane**: type of machine used for lifting, loading and unloading cargo from and on ship.
- **Forecastle**: located on the bow of the ship to secure the docking process.
- **Funnel**: used to expel boiler steam or smoke or engine exhaust.
- **Rudder**: device for steering the ship.
- **Main deck**: the principal deck of the vessel.
- **Super structure**: is an upward extension of an existing structure above main deck.
- **Holds**: part of vessel that carries the cargo.
- **Engine room**: including fuel tanks, water tanks, ballast tanks and storage tanks.
- **Bow thruster**: is transversal propulsion device built into or mounted to the bow of a ship.

**Trucks:**

Is a motor vehicle designed to transport cargo. Trucks vary greatly in size, power, and configuration. Commercial trucks can be very large and powerful.

Parts:

- **Wheels**: a circular frame or disk arranged to revolve on an axis, as on or in vehicles.
- **Brakes**: A device for slowing or stopping motion, as of a vehicle, especially by contact friction.
- **Safety and support systems**: control in all parts of truck for example, tire-pressure monitoring, camera system.
- **Engine**: a machine that converts energy into mechanical force or motion.
- **Cab**: the front part of truck, where the driver sits.
- **Control Cables**: for coupling or contacting the cars.
- **Transmissions parts**: provide the truck with tools for movement for example, Gearboxes, Drive axles.
- Valves: any device for controlling the flow of a liquid, gas, or other material. For example, air valve, water valve, tire valve.
- Fuel tanks: tanks that are provided with fuels to operate the truck.
- Chassis: The frame or body of a truck.
- Storage tanks: tanks that store LNG.

**Storage Module:**

Storing goods or the state of being stored with some systems that provide the integration management for this product or this vehicle also.

- Safety system: is a tool used to help keep people, vehicles and the environment safe. These systems are different for example safety system in trucks, also safety systems in ships, etc.
- Cooling mechanism systems: a mechanism for keeping something cool. These systems are different for example cooling by air, or water, etc.
- Regasification system: a closed-loop recirculation system with an air tower. Air towers have been used to reduce the heat of an industrial process system by exchanging the higher temperature of the process cooling system with the lower ambient temperature. However, the Freeport LNG air tower serves a heating function.
- Boil-off Gas Reliquefaction: when sending out gas for its customers, LNG continues to boil off and must be compressed and sent to sales, so we need the boil-off gas reliquefaction unit to capture the boil-off gas, convert it back into liquid
- Insulation: The two biggest enemies of industrial insulation performance, moisture (liquid and vapour) and fire. So we have some insulation systems for example, thermal Insulation, vacuum insulation.
- Docking mechanism for unloading/loading: a practice in the logistics of unloading materials from an incoming semi-trailer truck or railroad car and loading these materials directly into outbound trucks, trailers, or rail cars, with little or no storage in between.
- Vehicle tracking system: combines the use of automatic vehicle location in individual vehicles with software that collects these fleet data for a comprehensive picture of vehicle locations. Modern vehicle tracking systems commonly use GPS technology for locating the vehicle.
Chapter 7 Reusability

The system that has been created is based on the needs of companies and society with regards to the public functions within that society. The system is modelled in such a way that the function facilitates the basic public function needs for companies and society. The system could be reused in companies. The system provides in the designing structure of vehicles for our stakeholders like vehicle companies. The proposed system for providing LNG vehicles can be used for providing related needs of any organization for transportation. Abstracts of the functional decomposition can be used as a basis for re-designing any system related to transportation system. The proposed functional decomposition provides a clear distinction between functions. This allows for reusability of certain functions within related domains or re-applying the general structure of functions in other domains by making minor adaptions. The first decomposition function can be reused and allocated to physical components to transportation system target levels for many sorts of systems. The idef0 of A.3.2 describes a general pattern in which instructions for achieving transport system target levels to other functions are produced; these instructions are based upon data records of other functions connected to external controls. This pattern is generally applicable to many systems where design is required. In our safety and maintenance system, we provide a good system to be applicable not only for LNG transport but also to other systems of the transportations. In our triad system for LNG, we tried to make good system to reuse it in applications related to the transport systems because our integrated system is valid to other systems of transportations related to infrastructure and vehicle design.
Chapter 8. Conclusions

The system that has been created is based on the needs of companies and society with regards to the public functions within that society. The system is modelled in such a way that the function facilitates the basic public function needs for companies and society. The system provides in the designing structure of vehicles for our stakeholders like vehicle companies. The “Provide LNG Vehicles” system is responsible for transporting LNG from the recovery location towards the consumer using safe and efficient transportation techniques. We have some goals to achieve it during our project such; provide storage units for the transportation vehicles driving on LNG to replace their normal petrol tanks, of which the design can be based upon transportation vehicles, the long term goal is to transport LNG safely and securely using various types of vehicles depending on location and distance to be travelled. This report provides a functional and physical architecture of a LNG system. Both functional and physical architectures are integrated with other LNG design’s architectures. This integration provides a better insight in the system’s interactions with other LNG design systems. In this way it is possible to benefit from the functions, which are performed by other teams.

The system is designed to be as robust as possible. The system is designed to LNG synchromodal transportation networks for storage and distribution of LNG to mid-scale and small-scale markets. The designers should consider within the time frame of designing, building the priority to the technology to be first. Therefore multiple options for the components are given. This gives the ability to the designer to use the systems architecture not only in the near future, but also in long term. We consider that the continuous improvement in our new design in the next future is fully committed to achieving the goal of designing of our system for more benefits for all stakeholders.
Chapter 9. References


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1. Introduction

This document presents a suggested solution to the given case, that is Next Generation of Urban Agriculture. Nevertheless, we slightly redefined problem to reflect the true value of it.

This document consisted of five major parts, problem & solution, LCA, social structure, ethical considerations and solution assessment according various possible future scenarios.

Our team declare that work was performed honestly and clearly with no plagiarism whatsoever. All information sources are referenced and calculations detailed following logical links.
2. Problem & Solution

This section describes the problem we identified and our sustainable design in detail we are about to implement.

2.1. Problem

Lack of fresh vegetables in densely populated areas at affordable prices. Up to 90% of the final cost of vegetables is contributed to extensive. It takes long time, and vegetables reaching final consumer are not fresh. Moreover, agriculture utilize huge areas of land that are susceptible to land erosion, and last but not least, consumes a lot of unnatural substances that pollutes soil and products (i.e. pesticides, herbicides, fertilizers, etc.). All these factors contributes to high food prices, relatively low quality foods and we believe that it is not the most sustainable business model.

2.2. Solution

To tackle the problem we are going to build a greenhouse producing fresh vegetables daily in one of the major cities in moderate to cold climate areas like; New York, Boston, or Toronto just to name a few.

Agriculture requires relatively large areas and land is expensive in cities, therefore, our core innovation is to construct a greenhouse on top of currently existing buildings. This poses a major challenge in finding a suitable site.

As a first choice we are going to produce tomatoes due to its high demand and well-established technologies. Nevertheless, we do not reject the idea of producing a variety of crops in due course. Following best farming practices we envision hydroponic production, i.e. growing vegetables in water media enriched with vital nutrients and fertilizers. This is the crucial factor in our solution, due to weight limitations a building can support. On the other hand, currently most greenhouses utilize hydroponic; it is considered a best practice up to date.

On top of everything, we have to ensure economic viability of the project. Currently, up to 90% of the final food price is attributed to transportation and retailing. By our estimations, bringing production site near consumption, we eliminate the need of transportation and thus, it enables us to sell tomatoes at competitive price. Moreover, it allows more efficient re-use of packaging, further decreasing the price of the final product and its environmental impact.

Nevertheless, we do not stop here. We envision to eliminate retailers and sell our production by ourselves. Moreover, we foresee a possibility to cut expenses even further by
social innovations. We divide our social innovations into two major groups: social services and workforce management.

We perceive the fact that we are local producers and we have to make strong social ties in order to succeed in our business. We are striving to be producers of choice for our customers on local scale.

First, we are going to be open to society. We are going to devote a part of a farm as common area, where anybody could visit and see how a modern greenhouse functions. Moreover, we are going to create a green corner that would serve as a small park, where families could relax and hang out. All this would make our business recognizable and serves towards a positive image in the local community, and in general bring citizens closer to nature.

On top on that, we are going to offer rent service: we are going to devote a part of the farm, following the demand, where people are able to grow their own vegetables by themselves. They will be allocated a patch of land where they can grow whatever they want. We realize that not everybody is capable to run their own farm, therefore, for those who are interested we will offer agriculture services and/or workshops to teach how to take care of their own garden. Once again, we believe that it will serve our public image and grants us competitive advantage against classical producers.

Our second major social innovation we are planning to employ is to include socially vulnerable groups in running a greenhouse. Agriculture is activity that requires relatively much of low-skilled workforce. Therefore, we see a possibility to benefit from three target groups: people re-integrating into the job market, people sentenced for community works, and people from elder houses.

Elder people usually spend a vast majority of their time in a retirement home or nursing home. We envision that these people could really benefit from spending more time away from their daily environment. We want to provide a place were they can spend time in a green environment while at the same time provide in their own vegetable need.

For contracting community-sentenced people we hope to come to an agreement with local authorities by opening a small food shelter for poor people. In this way we are provided with relatively cheap labor force while also taking care of the people in need. We estimate that a small part of the vegetables harvested by people sentenced to community work goes to the food shelter. People re-integrating into the work market may receive minimal wage or receive payment in other ways. In this way, they do not have to live on welfare. Furthermore, these people are gradually getting accustomed to being back in a work environment.

In all cases it is a win-win situation for both partners. We receive relatively cheaper workforce and positive social image in the local community and socially vulnerable groups
benefit as well. It is just a starting point for our social cooperation and we believe in due course we will be able to include even more different people who could work in the farm under supervision of a few experts.

2.3. Limitations

Up to date, there are only two rooftop greenhouse farms around the world. The second one opened less than 6 months ago (both of them are located in Quebec, Canada). The major limitation, is a difficulty in finding a suitable building to place a rooftop farm on. It must have a flat rooftop and relatively large surface area: light industries are the first choice, for example distribution centers, warehouses, etc.

This limitation suggests that we have to be quick in securing good spots. Also, it suggests that first expansion phase should be ‘cherry-picking’ of the best spots, say one per town and only then scout for less suitable but acceptable areas to expand our business further. Nevertheless, we should keep in mind that this is always going to be a local business and we do not aim to replace classical farmers; up to date there are no sustainable solution is securing large areas required for large production of agriculture products in urban areas.

Another obstacle that is currently in tact is legislations. To produce fresh food for retailing one has to do that on the land that is allocated for agriculture purposes, while lots in the urban areas, cities, are destined as residential or industrial purpose. Therefore, local authorities must first be persuaded to issue required legislations to produce foodstuffs in urban areas.
3. Social structure

We envision seven major stakeholders in our project (Figure 1). They are all equally important and failing to serve one of their interests puts our solution at risk.

As mentioned above, permits to produce foodstuff for retailing are of utmost importance and, therefore, legal authorities must be convinced by our idea in order to issue legislations. It heavily depends on the exact location chosen; therefore, it is too early to specify it further.

Investors are of course major stakeholders. We have to secure funding to implement our idea. To the best of our knowledge, the project is expected to be feasible and start generating profit in 2 years after construction is finished and estimated investment sum is around $2m. In our personal point of view it is attractive proposition with relatively low risks, therefore, we think that securing investments should not be extremely difficult.

Property owners are also included in our solution. We first have to find a suitable location and secondly, convince property owners to allow us building a greenhouse on their houses. Having an extra structure on the currently existing house benefits the house owner in (i) reduced expenditures for heating, (ii) reduced amount of wastewater and (iii) reduced CO₂ emissions. Farm on the rooftop serves as extra heat insulation layer, and it uses water and carbon dioxide in the production of vegetables, therefore, property owners benefits of having a farm on their rooftop. As further leverages in negotiations, extra financial incentives or production at reduced costs may be used.
Best engineering and architectural solutions are of utmost importance in our solution. Basically, we want to put an extra weight on the rooftop that was not designed for doing so. Architects and engineers must be able to make a greenhouse as light as possible in order not to damage current structure and ensure maximum safety during operations. In some cases upgrades for the structure may be introduced if needed, but that heavily depends from case to case.

Of course, workforce is a major stakeholder in our business model. As basically it is in every business solution. As presented in section 1.2 we are going to innovate with our workforce including unconventional social groups, therefore, these stakeholders are even more important. Detailed solution is presented in section 1.2.

And last but not least, consumers of our products are a must for the success as well. As a first choice, we aim for medium sized consumers in urban areas, such as restaurants and cafeterias. We plan by reaching our customers by classical marketing means, eye-to-eye sales, as well as by Internet marketing. Once again, this report is not aimed towards economic viability of the project but sustainability in general; therefore, marketing plan is not yet elaborated in our sustainable design.
4. Life Cycle Assessment

The Life Cycle Assessment evaluates four major steps in vegetable production in the greenhouse. For the considered case, tomatoes are chosen as a crop. The purpose of the LCA is to be able to compare flows between classical greenhouse farm and urban greenhouse farm, which is defined as a greenhouse constructed on a rooftop in urban area.

Four major steps are identified in the lifecycle that is (i) construction of greenhouse, (ii) production of tomatoes, (iii) packaging and distribution of vegetables and (iv) decommission of the structure.

4.1. Assumptions

Two general assumptions are accepted while comparing classical greenhouse versus urban. First, we assume that decommission costs are equal, thus, this factor was not included in the lifecycle analysis.

Second, to the best of our knowledge, there are no actual data on greenhouse construction in the urban case. The best data we found is estimation that it costs 66 % more to build a rooftop farm than classical, therefore, we assume, that all flows increased are 66 % higher. Nevertheless, it is important to point out that this is the most pessimistic case, as most of the increase in price is due to legislation and architectural planning over extended period of time.

4.2. Functional Unit

As a functional unit, we chose tomato yield as t·ha⁻¹·y⁻¹.
4.3. LCA of classical greenhouse

Tables 1-3 presents input required on every lifetime stage, while Table 4 summarizes environmental factors of each stage per functional unit.3

Table 1. Estimated construction phase input per ha of greenhouse.

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>127.97</td>
<td>kg</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.38</td>
<td>m3</td>
</tr>
<tr>
<td>Glass</td>
<td>526.93</td>
<td>kg</td>
</tr>
<tr>
<td>Polyester</td>
<td>33.16</td>
<td>kg</td>
</tr>
<tr>
<td>Steel</td>
<td>513.56</td>
<td>kg</td>
</tr>
<tr>
<td>Transport</td>
<td>77.40</td>
<td>tkm</td>
</tr>
<tr>
<td>LDPE</td>
<td>3.31</td>
<td>kg</td>
</tr>
<tr>
<td>Polyester</td>
<td>0.30</td>
<td>kg</td>
</tr>
<tr>
<td>PVC</td>
<td>0.46</td>
<td>kg</td>
</tr>
</tbody>
</table>

Table 2. Estimated production input per per t·ha⁻¹·y⁻¹.

<table>
<thead>
<tr>
<th>Production</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>29.9</td>
<td>GJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>272</td>
<td>kWh</td>
</tr>
<tr>
<td>Water</td>
<td>0.969</td>
<td>kg</td>
</tr>
<tr>
<td>Rockwool</td>
<td>18700</td>
<td>L</td>
</tr>
<tr>
<td>Calcium Nitrate – Ca(NO₃)₂</td>
<td>11.7</td>
<td>kg</td>
</tr>
<tr>
<td>Potassium Nitrate – KNO₃</td>
<td>11.9</td>
<td>kg</td>
</tr>
<tr>
<td>Potassium Sulphate – K₃PO₄</td>
<td>1.5</td>
<td>kg</td>
</tr>
<tr>
<td>Potassium Chloride – KCl</td>
<td>1.13</td>
<td>kg</td>
</tr>
<tr>
<td>Magnesium Sulphate – MgSO₄</td>
<td>3.18</td>
<td>kg</td>
</tr>
<tr>
<td>Ammonium Nitrate – NH₄NO₃</td>
<td>0.412</td>
<td>kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
</table>
Table 3. Estimated input for packaging and distribution per t·ha⁻¹·y⁻¹.

<table>
<thead>
<tr>
<th>Element</th>
<th>GW (kg CO₂ eq.)</th>
<th>AD (g SO₂ eq.)</th>
<th>EU (g PO₄³⁻ eq.)</th>
<th>OD (mg CFC-11 eq.)</th>
<th>CED (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>12000 tkm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity (cooling)</td>
<td>0.743 kWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDPE (packaging)</td>
<td>100 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Environmental impacts of classical greenhouse in each life stage per functional unit, t·ha⁻¹·y⁻¹.

<table>
<thead>
<tr>
<th>Element</th>
<th>GW (kg CO₂ eq.)</th>
<th>AD (g SO₂ eq.)</th>
<th>EU (g PO₄³⁻ eq.)</th>
<th>OD (mg CFC-11 eq.)</th>
<th>CED (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>32</td>
<td>3.5</td>
<td>0.038</td>
<td>1.1</td>
<td>0.51</td>
</tr>
<tr>
<td>Agriculture production</td>
<td>300</td>
<td>1210</td>
<td>570</td>
<td>27</td>
<td>4.66</td>
</tr>
<tr>
<td>Packaging &amp; Distribution</td>
<td>392</td>
<td>1930</td>
<td>266</td>
<td>74</td>
<td>11.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>692</td>
<td>3140</td>
<td>836</td>
<td>101</td>
<td>16.26</td>
</tr>
</tbody>
</table>

GW - Global warming potential, AD - acidification EU – eutrophication, OD - ozone depletion, CED - cumulative energy demand.

4.4. **Comparison between classical and urban greenhouse**

Tomatoes produced in an urban greenhouse require less heat compared to a classical farm due to: (i) higher urban temperatures in the night time, (ii) utilization of residual heat of the mounted building, (iii) re-utilization of waste water.

Nevertheless, major savings occur in the Packaging & Distribution phases as tomatoes reach consumers directly and packaging is easily re-used. Taking into consideration theses factors, Table 5, provides absolute numbers of environmental factor of three major steps, while Table 6 indicates differences between classical and urban farms outlining absolute and relative saving.

Table 5. Environmental impact of urban greenhouse per functional unit.

<table>
<thead>
<tr>
<th>Element</th>
<th>GW (kg CO₂ eq.)</th>
<th>AD (g SO₂ eq.)</th>
<th>EU (g PO₄³⁻ eq.)</th>
<th>OD (mg CFC-11 eq.)</th>
<th>CED (MJ)</th>
</tr>
</thead>
</table>
Table 6. Comparison of environmental impact of urban and classical farms per functional unit.

<table>
<thead>
<tr>
<th>Element</th>
<th>GW (kg CO$_2$ eq.)</th>
<th>AD (g SO$_2$ eq.)</th>
<th>EU (g PO$_4^{3-}$ eq.)</th>
<th>OD (mg CFC-11 eq.)</th>
<th>CED (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical farm</td>
<td>692</td>
<td>3140</td>
<td>836</td>
<td>101</td>
<td>16.26</td>
</tr>
<tr>
<td>Urban farm</td>
<td>313</td>
<td>1050</td>
<td>490</td>
<td>26.8</td>
<td>5.16</td>
</tr>
<tr>
<td>Absolute savings</td>
<td>379</td>
<td>2090</td>
<td>346</td>
<td>74.2</td>
<td>11.1</td>
</tr>
<tr>
<td>Relative savings (%)</td>
<td>221</td>
<td>299</td>
<td>170</td>
<td>376</td>
<td>315</td>
</tr>
</tbody>
</table>

GW - Global warming potential, AD - acidification EU – eutrophication, OD - ozone depletion, CED - cumulative energy demand.

4.5. Life Cycle Assessment Conclusions

Table 6 presents us with the savings we achieve while employing urban farms instead of classical one. Global warming potential is decreased by factor 2.2, soil acidification potential almost by factor 3, while eutrophication, ozone depletion and cumulative energy demand by factor 1.7, 3.7 and 3.1 respectively. On average, we perform better by factor 2.7, moreover, cumulative positive effect is even greater.

In the light of the facts, urban farm is much more environmentally friendly than the classical farm due to the fact that goods are being produced close to consumption site. It cuts the needs of transport and extra storage in distribution warehouses, as well as allows multiple uses of packaging means, thus, further reducing environmental impact of urban farm.
5. Ethical considerations

There was a difficult task to find an ethical dilemma in our proposed business model. We think that the major plight of the plan is our unconventional workforce solution.

In one way we are going to take advantage of a group of people who is going to perform work for which they will not get paid directly. Therefore, one may say we are enslaving them. On the other hand, we are imposing mechanisms to compensate for their labour: not directly to them but to the managing authorities, either it would be local government, elder homes, or some other authority. Detailed compensation mechanisms are mentioned in the section 1.2.

If our calculations are correct we are going to provide food at much lower prices than current suppliers. Nevertheless, we are striving for economic success. We will not be able to sell products at lower prices which would result in relatively high profit margins. Nevertheless, we are taking into consideration support for local communities via inclusion of unconventional workforce also serving as a part of the solution. Even more, we are providing social services, open greenhouse, and rent options; keeping profits in the local community.

What is more, we are not only including socially vulnerable groups as possible workforce, we also are planning to open food shelter for homeless people.

We believe that key to our success is local community therefore all the social schemes aims in taking care of local community and establishing good corporate image in order to be sustainable.
6. Scenarios

In assessing the four scenarios, the focus will lie on three factors we think are the most relevant for our case. These three factors are: the rate of urbanization, trading, and the impact on regular agriculture.

6.1. Global Orchestration

“The recognition that many of the most pressing global problems seem to have roots in poverty and inequality evokes fair policies to improve the well-being of those in poorer countries by removing trade barriers and subsidies. Environmental problems are dealt with in an ad-hoc manner since people generally assume that improved economic well-being will create both the demand for and the means to achieve a well-functioning environment. Nations also make progress on global environmental problems, such as greenhouse gas emissions and depletion of pelagic marine fishing. However, some local and regional environmental problems are exacerbated. The results for ecosystem services are mixed. While human well-being is improved in many of the poorest countries, a number of ecosystem services deteriorate by 2050.”

In this scenario trade is expanded globally, driven by removal of subsidies and greatly increasing demands for goods and services around the planet. Local ecological knowledge is replaced by uniform methods. By 2030 many small time farms are consolidated into large agricultural operations. Since our business is mostly focused on the local market, a more global-minded market will endanger our existence. On the other hand, rapid urbanization significantly declines wetlands suitable for agriculture. As more and more people move from the countryside to the city, the demand for affordable and healthy food also increases. Since regular agriculture can’t keep up with the demand, a great opportunity lies here for the construction of more rooftop greenhouse in order to provide a steady supply of healthy and affordable food.

6.2. Order from Strength

“The policies enacted in this scenario lead to a world in which the rich protect their borders, attempting to confine poverty, conflict, environmental degradation, and deterioration of ecosystem services to areas outside those borders. Poverty, conflict, and environmental problems often cross the borders, however, impinging on the well-being of those within. Protected natural areas are not sufficient for nature preservation or the maintenance of ecosystem services.”
In this scenario the developed regions like the US and the EU are turning inward, striving to preserve national security. Increasing protectionism makes it more difficult to trade between regions. This will be beneficial for our local business. Since goods from the outside are more expensive people will tend to buy their goods from local venues. In an attempt to create more livable land, food production is moved to poor countries. Conflict in poor areas affected their ability to produce food, causing food prices to rise. Our business of rooftop greenhouse could really attribute to both problems of less agricultural land and high food prices. By building more greenhouses on rooftops, food prices can be kept at reasonable level without having to sacrifice expensive land to regular agriculture.

6.3. Adapting Mosaic

“In this scenario, lack of faith in global institutions, combined with increased understanding of the importance of resilience and local flexibility lead to approaches that favor experimentation and local control of ecosystem management. The results are mixed, as some regions do a good job managing ecosystems and others do not. High level of communication and interest in learning leads regions to compare experiences and learn from one another. Gradually the number of successful experiment begins to grow. While global problems are ignored initially, later in the scenario they are approached with flexible strategies based on successful experiences with locally adaptive management. However, some systems suffer long-lasing degradation.”

This scenario focuses on the lack of faith in global institutions. Global trade barriers for goods were increased while trade barriers decreased within regional blocs such as the EU. Poor cooperation will initially lead to climate change affecting regular agriculture. This will be positive for our case since we act on a local scale in a confined space. If trade barriers are increased, the demand for food produced locally, and thus cheaper, will rise. Damage to urban centers due to climate causes more people to move out of the city. In order to keep the city interesting for people, our greenhouses could be employed as sort of “urban wilderness”. By providing a greenhouse and the necessary services, people could have their own rural rooftop or patio without having to move out of the city.

6.4. TechoGarden

“The use of technology and the focus on ecosystem services is driven by a system of property rights and valuation of ecosystem services. In this scenario, people push ecosystems to their limits of producing the optimum amount of ecosystem services for humans through the use of technology. Often, the technologies they use are more flexible than today’s environmental engineering and they allow multiple needs to be met from the same ecosystem. Provision of ecosystem services in this scenario is high worldwide, but flexibility is low due to high
dependence on a narrow set of optimal approaches. In some cases unexpected problems created by technology and the erosion of ecological resilience lead to vulnerable ecosystem services, which are subject to interruption or breakdown. In addition, success in increasing the production of ecosystem services often undercuts the ability of ecosystems to support them, leading to surprising interruptions of service provision and collapse of some ecosystem services. These interruptions and collapses sometimes have serious consequences for human well-being."

The TechnoGarden scenario mainly focuses on looking for profits in working with nature – “natural capitalism”. This also leads to increasing governmental control through “green” taxes in an attempt to reduce pollution. Because of the negative consequences in intensive agriculture, subsidies for agriculture purposes are removed and the demand for ecological agriculture increases. Our rooftop greenhouses will greatly benefit from the withdrawal of widespread agriculture subsidies since it can compete on a level playing field. The development of green agriculture will spread most rapidly in western countries. New urban areas will be built in a way that is will have low or positive impact on the ecosystem. This will create great opportunities for more rooftop greenhouses. The removal of agricultural subsidies also leads to competition from developing countries since they have an increased ability to export agricultural goods.

6.5. Scenarios Conclusions

Table 7. Summary of key aspects of every scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Rate of Urbanization</th>
<th>Trading</th>
<th>Impact on regular agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Orchestration</td>
<td>Rapid urbanization</td>
<td>Expanded globally</td>
<td>Can’t keep up with demand; requires new techniques</td>
</tr>
<tr>
<td>Order from Strength</td>
<td>High in rich and poor countries</td>
<td>Regions turning inward</td>
<td>Create more liveable land</td>
</tr>
<tr>
<td>Adapting Mosaic</td>
<td>Reconnect with nature</td>
<td>Trade barriers increase</td>
<td>Affected by poor cooperation and climate change</td>
</tr>
<tr>
<td>TechnoGarden</td>
<td>Integrate urbanization with nature</td>
<td>Natural capitalism</td>
<td>Demand for ecological agriculture</td>
</tr>
</tbody>
</table>
We can briefly sum up and draw conclusions what will happen to our business model in each of the scenarios. First two scenarios project rapid growth of cities, therefore, it benefits our business largely as demand for fresh vegetables will increase. If more proactive attitude towards ecological sustainability would take over, people will seek to reconnect with nature. This is tackled by our social services, such as openness towards public, a green corner in our greenhouse and possibility to rent a patch for everyone. In this way people could feel connected with nature by having their own “backyard wilderness” in the form of a greenhouse filled with vegetation of their choosing. We will provide a full service of building and maintaining the greenhouse as indicated in our Solution section.

Considering global trade situation, we see our business model robust enough no matter what the future will bring. We are going to remain local producers; therefore we benefit more if global trade is restricted, nevertheless, we think that agriculture is a trade not prone to this trend, because products are sensible to the travel time. Moreover, it is estimated that green taxes may be introduced to even further reduce pollution, therefore, we benefit greatly compared with classical farms.

Last criterion that we think is important to our business is how every possible future may affect regular farmers, i.e. our direct competitors. In case of Global Orchestration scenario, it is estimated that regular farmers will not be able to keep up with demand, therefore, it is a win situation for our business. If Order of Strength takes place, farmers are forced to create more liveable land by reducing emissions; therefore, we gain competitive advantage. Adapting Mosaic scenario projects that regular farmers will be affected badly by global climate change, making greenhouses even more robust as we are able to control production environment completely. Lastly, in case of Technogarden circumstances, regular farmers are forced towards ecological production, and our production will be already ecological, therefore, it serves to our benefit.

To sum up, no matter what the future will bring, our business is expected to strive if we will be able to maintain good social ties with local community and be up to date with the most advanced farming technologies.
7. Conclusions

To sum up, we have presented a solution that seems sustainable to us. By implementing it, we are striving to ensure food security in densely populated areas, provide fresh vegetables to local residents and do that generating profit to our shareholders. Moreover, our rooftop farms outperform classical farms in environmental aspect on average reducing different types of pollutions by factor 2.7, nevertheless, cumulative positive environmental impact is even greater. In addition to that, we include a number of social innovations in order (i) to ensure positive local image and (ii) to bring down labour cost.

We strongly believe in our solution and we are ready to implement it in the real world.
8. References

