APPENDIX

Master Thesis

Louis Picarelle

Appendix A - List of Requirements

The list of requirements is divided into nine chapters. The chapters stand for the first abbreviation in the requirement name. The second group of letters is about general or subsystem bound requirements. Final-ly the “R” or “W” stand respectively for Requirements or Wish.

Whenever a “_B_” is added in the name, the requirement is also applicable to the backbone.
At various points in the project the scope has been adjusted. Thus, some requirements have become redundant with respect to the scope. Nevertheless, they remained in the list of requirements.

Performance

PER_GEN_R_01	The product needs to produce 0.14kg MeOH per day
PER_GEN_R_02	The product needs to capture 0.1925 kg of CO2 per day
PER_GEN_R_03	The product needs to produce and capture 8.75 grams of H2
PER_B_GEN_R_04	The product froms a sturdy attachment point for all unit operations & sensors
PER_GEN_R_05	The product integrates thermal management: coolers, recuperators, heaters, etc
PER_B_GEN_R_06	The product is to be mounted on a solar racking system wich carries a 300W PV panel (1956x992x50mm)
PER_GEN_R_07	The product may not rest on the ground

PER_B_DAC_R_01	The product needs to contain 1.08kg of Sorbent (Daviseal+PEI)
PER_DAC_R_02	The DAC contains one fan which sucks air through the sorbent chambers
PER_B_DAC_R_03	The product needs to contain 2 sorbent chambers
PER_DAC_R_04	The sorbent must stay within its chamber
PER_B_DAC_R_05	The sorbent has total volume of 4.38liters (incl. void fraction of 0.5)
PER_B_DAC_R_06	The material needs to be CO2 resistant
PER_B_DAC_R_07	The material needs to withstand a temperature range of (environmental(-20)-120 degrees Celsius).
PER_B_DAC_R_08	The product needs to withstand an underpressure of 0.1bar up to 1 bar
PER_DAC_R_09	The DAC fan has a flowrate of 0.0371 M^3 of air per sec.
PER_DAC_R_10	The sorbent chambers must vacuumed until 0.1bar
PER_B_DAC_R_11	The material needs to be 100% H2O resistant

PER_B_AEC_W/R_01	The material needs to be 100% KOH resistant
PER_AEC_R_02	The product should house a total surface of cells which equals 364.58 square cm
PER_AEC_R_03	The KOH needs to stay within its chamber despite the connections.
PER_B_AEC_R_04	The product needs to withstand a pressure of 52 bar
PER_AEC_R_05	The cells are connected in series
PER_AEC_R_06	The KOH is connected by means of communication vessels
PER_B_AEC_R_07	The product needs to bear a total amount of KOH which equals a weight of 0.77 kg
PER_B_AEC_R_08	The product needs to contain 0.364l of KOH
PER_B_AEC_R_09	The material needs to be 100% O2 resistant
PER_B_AEC_R_10	The material needs to be 100% H2O resistant
PER_B_AEC_R_11	The material needs to be 100% H2 resistant

PER_MS_R_01	The product needs to withstand a temperature range between 70-250 degrees Celsius
PER_MS_R_02	The material needs to be CO resistant
PER_MS_R_03	The material needs to be CO2 resistant
PER_MS_R_04	The material needs to be 100% H2 resistant
PER_MS_R_05	The product needs to contain 41.8g of catalyst
PER_MS_R_06	The product needs to contain a tube which has a volume of 0.023 liters
PER_MS_R_07	The product needs to contain an electric heater
PER_MS_R_08	The material needs to be 100% H2O resistant
PER_MS_R_09	The material needs to be 100% CH3OH resistant

PER_B_DS_R_01	The material needs to withstand a temperature range between 70-100 degrees Celsius
PER_B_DS_R_02	he material needs to be 100% CH3OH resistant
PER_B_DS_R_03	The product needs to contain a wick
PER_B_DS_R_04	The material needs to be 100% H2O resistant

PER_B_TA_R_01	The product needs to contain a H2 tank with a volume of 1.312 liters (1 hour buffer)
PER_B_TA_R_02	The product needs to contain a CO2 tank with a volume of 0.786 liters (2 hour buffer)
PER_B_TA_R_03	The product needs to contain a H2O tank with a a volume of 0.236 liters

Environment

ENV_B_GEN_R_01	The product must protect the subsystems from external influences
ENV_B_GEN_R_02	The product must not pollute the environment with any of its contents
ENV_B_GEN_R_03	The product must be leak tight
ENV_GEN_R_04	The product must involve all subsystems except for the solar system
ENV_B_GEN_R_05	The product needs to be UV resistant
ENV_B_GEN_R_06	The product must be placed in the desert (sunbelt region)

Life in Serivice

LIS_B_GEN_R_01	The product must function 20 years every day for approximately 7hours

Maintenance

MAI_B_GEN_R_01	The product must enable the user to access the DAC subsystem for the sorbent
MAI_B_GEN_R_02	The product must enable the user to access the AEC subsystem for both replacing the electrolyte and KOH
MAI_B_GEN_W_01	The product should enable the user to replace the electronical parts (fans, sensors, heater, actuator,...)

Target Production Cost

TPC_GEN_R_01	The complete product must not exceed a production cost of 137.5 euros for a quantity of 40.000 pcs.
TPC_GEN_R_02	The DAC accounts for 35.7 % of the total production cost
TPC_GEN_R_03	The AEC accounts for 18% of the total production cost
TPC_GEN_R_04	The MS accounts for 12% of the total production cost
TPC_GEN_R_05	The FM accounts for 9% of the total production cost
TPC_GEN_R_06	The CO accouonts for 18.3 % of the total production cost
TPC_GEN_R_07	The SOL account for 2.7% of the total production cost
TPC_B_GEN_R_08	The IC accounts for 2.5 % of the total production cost or 3.5 euros
TPC_GEN_R_09	The DS accounts for 0.7% of the total production cost
TPC_GEN_R_02	The MEOH must be produced at 350 euros per ton

Quantity

QUA_B_GEN_R_01	The product must be produced at an amount of 40.000 pcs or more
QUA_B_GEN_R_02	The product must be produced in batches.

Size and Weight

SaW_B_GEN_R_01	The product must weigh not more than 7kg

Reliability

REL_B_GEN_R_01	The product must not fail on pressure and temperature requirements

Safety

SAF_B_GEN_R_01	The product must protect the user from hot regions
SAF_B_GEN_R_02	The product must be self-explanatory with regard to danger (hot surface, toxic material, etc)
SAF_B_GEN_R_03	The product must have use cues for carriage
SAF_B_GEN_R_04	The product must have use cues for refill of content/hot swap of sub parts
SAF_B_GEN_W_03	The product must enable hot swap on the solar rack

Appendix B - Temperature and pressure overview

Sytem Overview
The overviews below provide a visual overview of where what pressure and temperature is applied in the backbone. This representation, also communicates where valves, sensors, canals, heating and cooling systems are to be placed. The design is in constant development, which means by this time the exact overview has been altered. Placement, types and amount of components determined have been changed. Nevertheless, the involved temperatures and pressures have been kept the same till this point. Figure 1 and 2 below provide an overview.

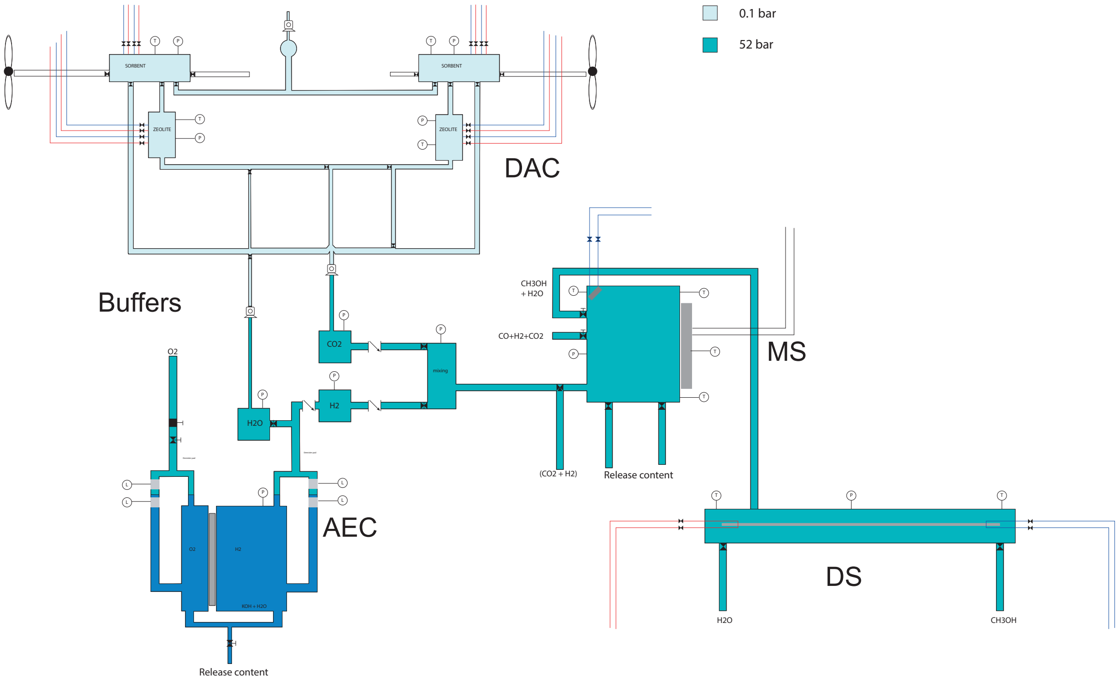


Figure 1. Pressure overview

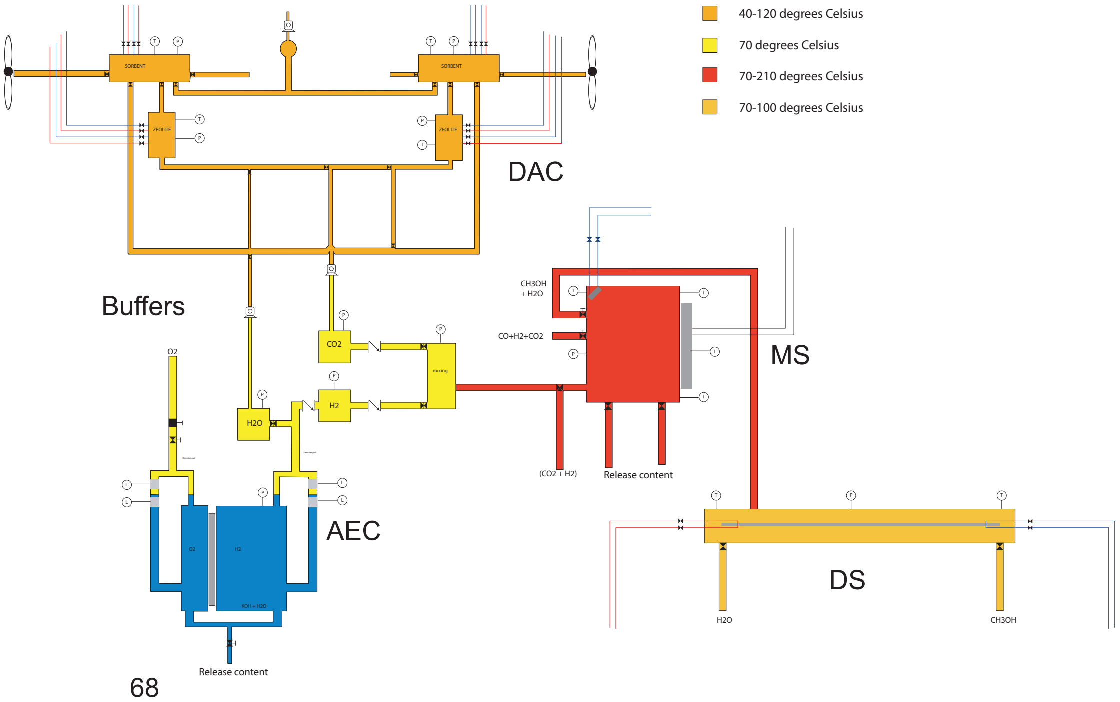


Figure 2. Temperature overview

Appendix C - Business Model Canvas

KEY PARTNERS

O&M
Security company
Installation company
Maintenance company
Solar company

R&D
NPK
University Twente
TUDelft
TNO
Tielo Tech
ZEF bv.

KEY ACTIVITIES

MEOH production

KEY RESOURCES

CO2
Sunlight
workers
Trucks/machines
Sunbelt location

VALUE PROPOSITION

Offer competitive renewable MEOH price

Easy numbering up

Not location bound

O2 production

Closure CO2 loop

Autonomous

Plug and play existing solar technology

Production of a negative emission fuel

CUSTOMER RELATIONSHIPS

MEOH distributors

CHANNELS

Media

CUSTOMER SEGMENTS

Environment
Society

COST STRUCTURE

R&D	**Installation**
Production	**Maintenance**
Assembly	**Collection**
Transport	**Safety**

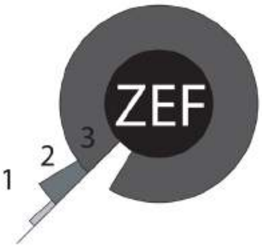
REVENUE STREAMS

Paying distributors
Subidy government
Negative emission EU

Appendix D - Customer Journey

The Customer Journey is based upon insights retrieved from the Business Model Canvas. The key-partners, activities and resources from the Business Model Canvas are used to define the stages in the life time of a micro-plant. These have been defined as the Installation, Maintenance and Operation phase. Each phase has been elaborated upon in four dimensions. Key activities, the users involved, possible problems, and finally the opportunities. The upper-left radial graph in the customer journey, communicates the importance of the phase in the life-time of a micro-plant. Figure 3 provides an overview of the findings.

CUSTOMER JOURNEY



1. INSTALLATION

🔑
TRUCK TRANSPORT
SOLAR PILE DRIVER
SUN BELT LOCATION
RACK INSTALLATION
SOLAR PANEL INSTALLATION
ZEF MICRO -PLANT INSTALLATION

🦷
TYPE OF SOIL
VEGETAION
REACHABILITY

✋
MACHNIES
WORKERS

💡
IMPROVE INSTALLATION SPEED

2. MAINTENANCE

🔑
SPOT PROBLEMS
PERFORM MAINTENANCE

🦷
LACK OF INFORMATION

✋
WORKERS/TRANSPORT

💡
HOT "SWAPABLE"
NIGHT
AUTONOMOUS SPOTTING

3. OPERATION

🔑
MEOH PRODUCTION

🦷
TEMPERATURE DIFFERENCE
ANIMALS ARE ATTRACTED
SAND
LIMITED CO2 CONCENTRATION
LEAKAGE TOXIC MATERIALS
MOISTURE

✋
TRANSPORT MEOH
TO DISTRIBUTOR

💡
H2O PRODUCTION

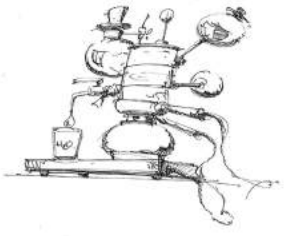


Figure 3. Customer Journey

Appendix E - Motivation parameter and limit choice

This appendix zooms in at the actual values of the limits used for the material search and the parameters chosen to base the iterations upon.

1. Narrow down the search area

The search area within CES level 3 can be narrowed down by applying limits. Based upon the defined challenges of the analysis phase, requirements are translated into material properties. Hereunder an overview, of how the requirements help to narrow down the search area by four limits.

A. Technical challenge pressure range

The pressure ranges from 0.1 to 50 bars in the backbone. Translated into material properties a high Yield Strength and Young's Modulus value are necessary. The higher the values the less material is needed to cope with the implied load cases. The maximum values are based upon the materials with the highest values in the database.

Applied limit

Yield Strength: 100- 6670 MPa
Young's Modulus: 10-12010 GPa

B. Technical challenge temperature range

The maximum involved temperatures range from ambient to 120 degrees in the DAC compartment. According to Tempelman, plastics are well suited for stiffness applications. Strength applications are more challenging since properties are strongly subjected to chemicals and temperature influences. Therefore a minimal service temperature of 200 degrees Celsius has been chosen.

Applied limit

Maximum service temperature: minimum of 200 and maximum of 250 degrees Celsius

C. Technical challenge chemical exposure to MeOH, O2, H2, H2O, CO2

CES has only restricted databases with respect to chemical resistance. Only vague boundary conditions are to be set. For this reason only the influence to water at room temperature is set to excellent. The specific resistance to the various chemicals has to be verified at a later stage.

Applied limit

Water: Excellent resistance

D. Financial challenge a backbone cost of 3.5 euros

Finally, a material as cheap as possible complying as good as possible with the above stated require-ments is to be found. Therefore, a cost price limit as low as possible has been applied as well.

Applied limit

Cost price: 0-15 euros

2. **Define parameters**
The result of the applied limits is a confined search area consisting of 168 out of 3968 materials. The second step is to look for the material which comes the closest to the ideal material properties within this search area. Thus, the next step is to define additional relevant parameters other than the ones which have been applied in narrowing down the search area. Hereunder a summation of the parameters used.

a. Parameters used by the limits
Yield strength, Young's Modulus, Maximum Service Temp, Excellent water resistance, Cost price

b. Density
Density is directly related to cost. Hence a light material is preferred over a heavy one.

c. Thermal Expansion
Since the backbone temperature ranges from ambient to 120 degrees Celsius, thermal expansion is to be avoided as much as possible. Stress concentrations may cause the backbone to fail.

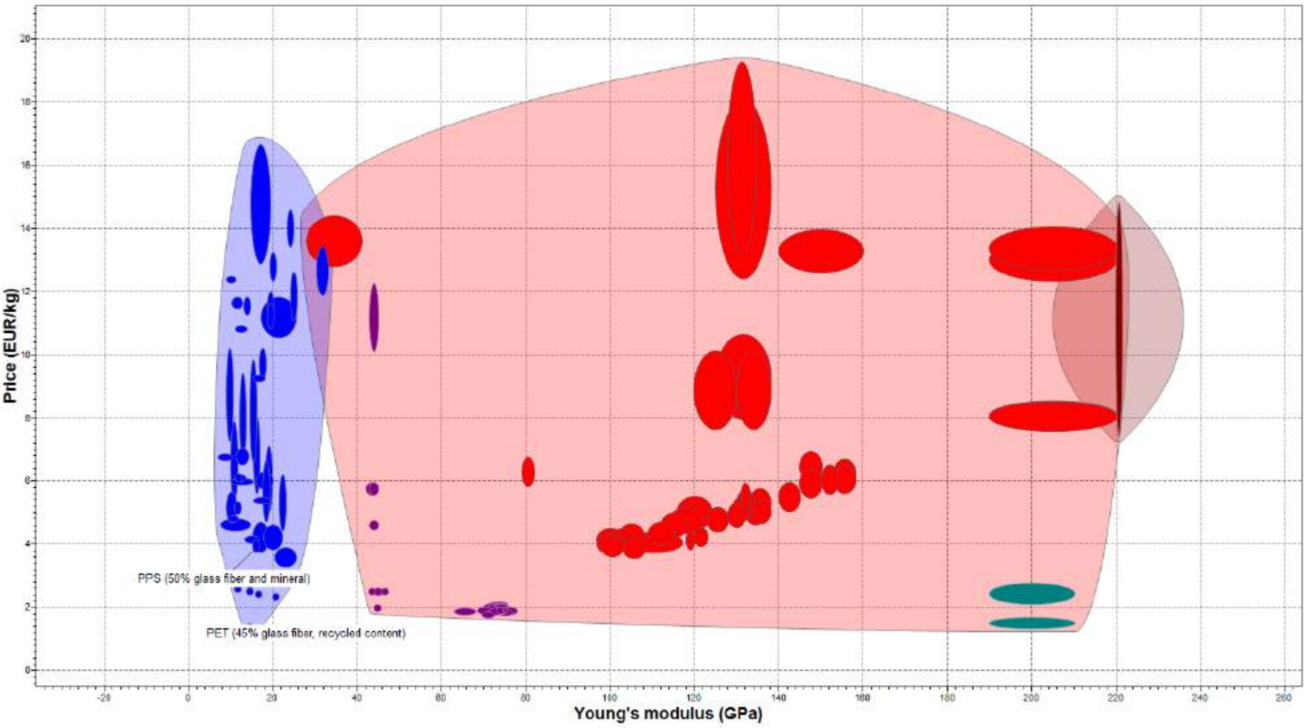
d. Thermal Conductivity
With regard to system efficiency, the backbone connecting all subsystems is to conduct as little heat as possible. Recuperation of heat is therefore a strong demand.

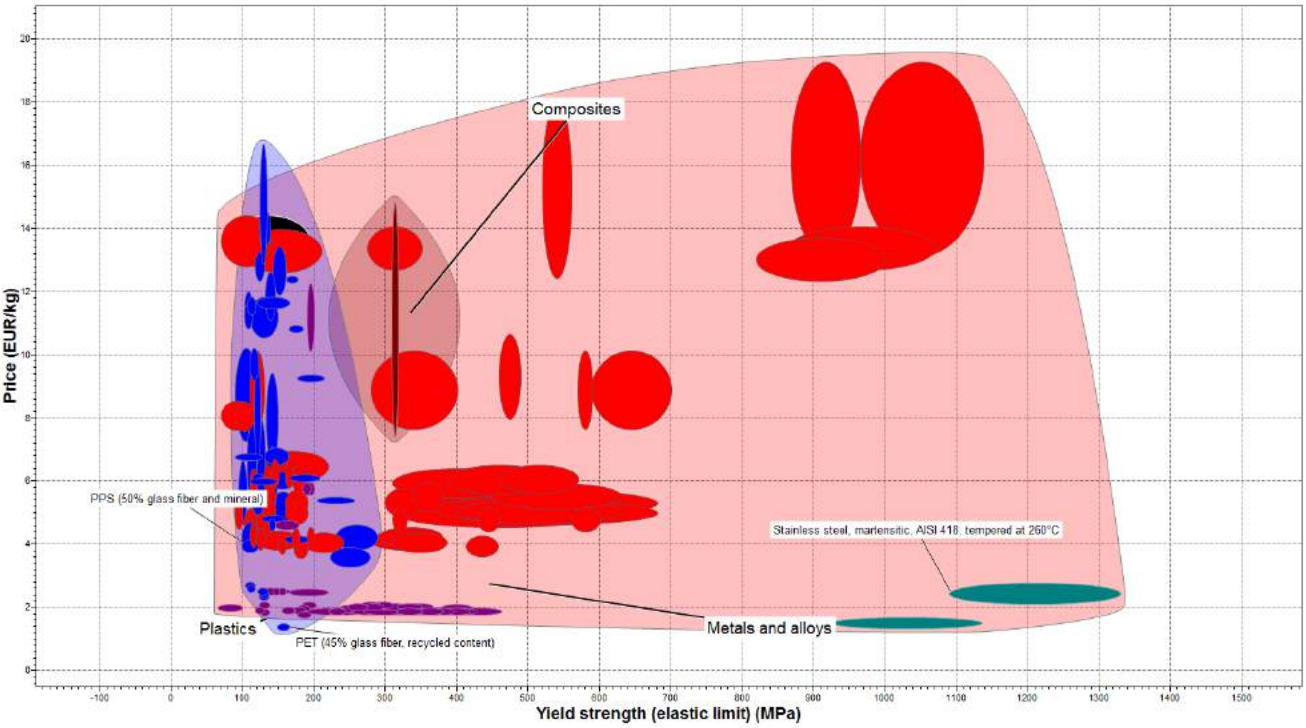
e. Chemical resistance other than H_2O

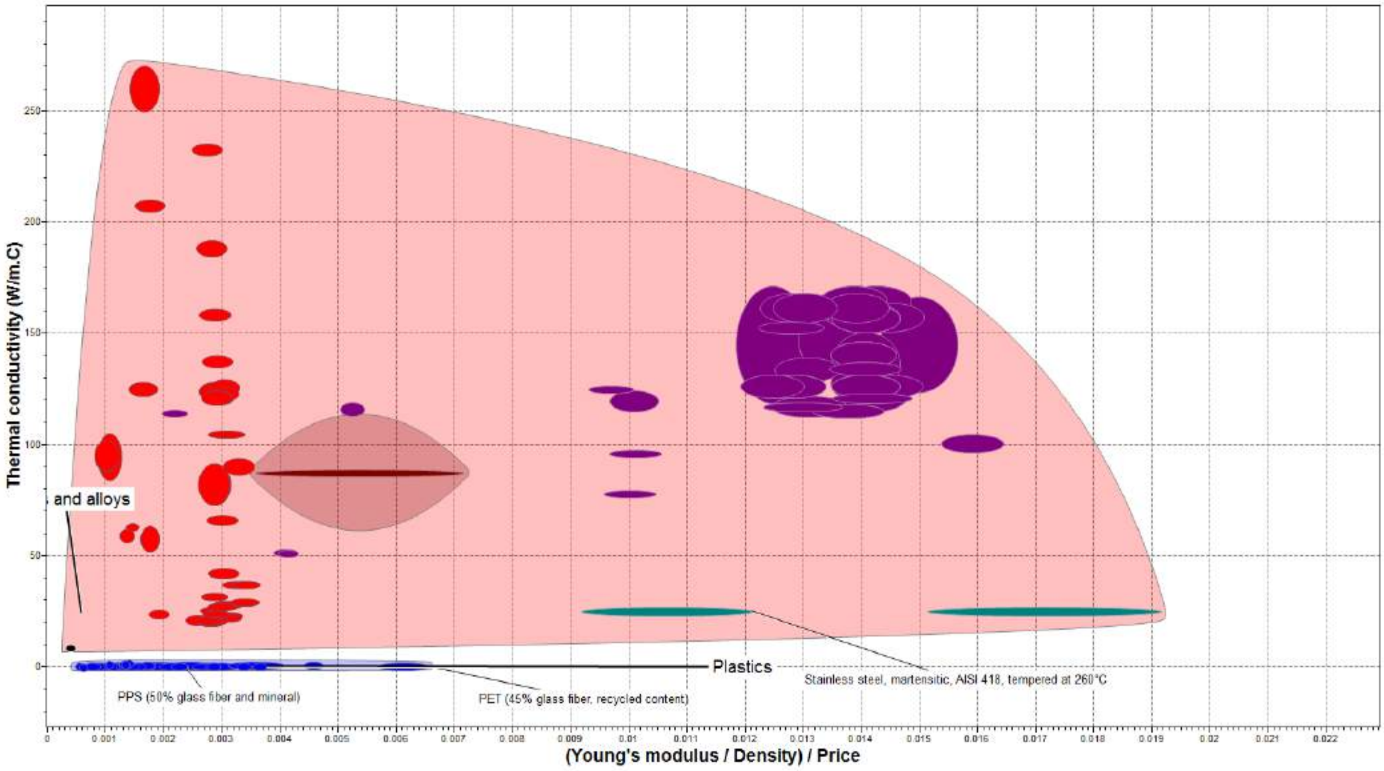
f. Ease and cost of manufacturability

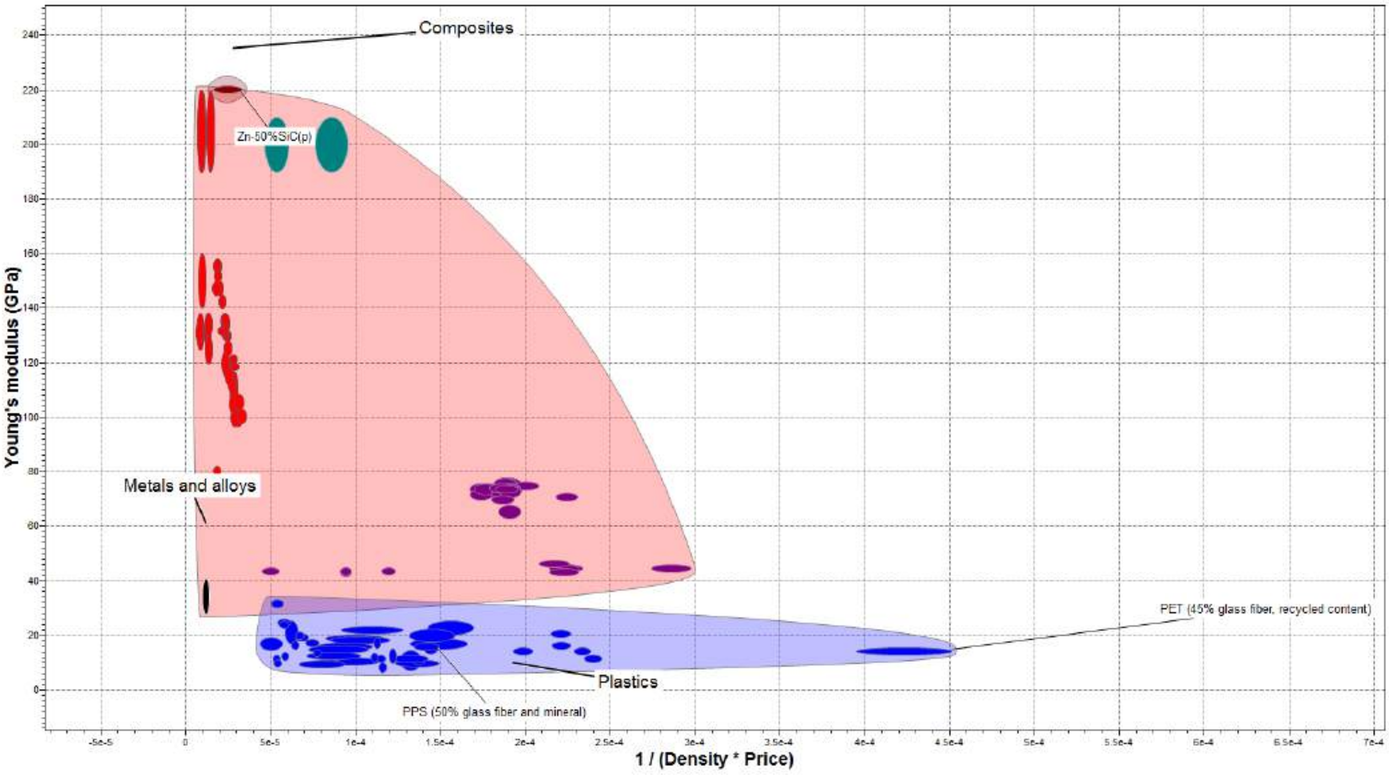
Appendix F - Iterations CES: Material plots

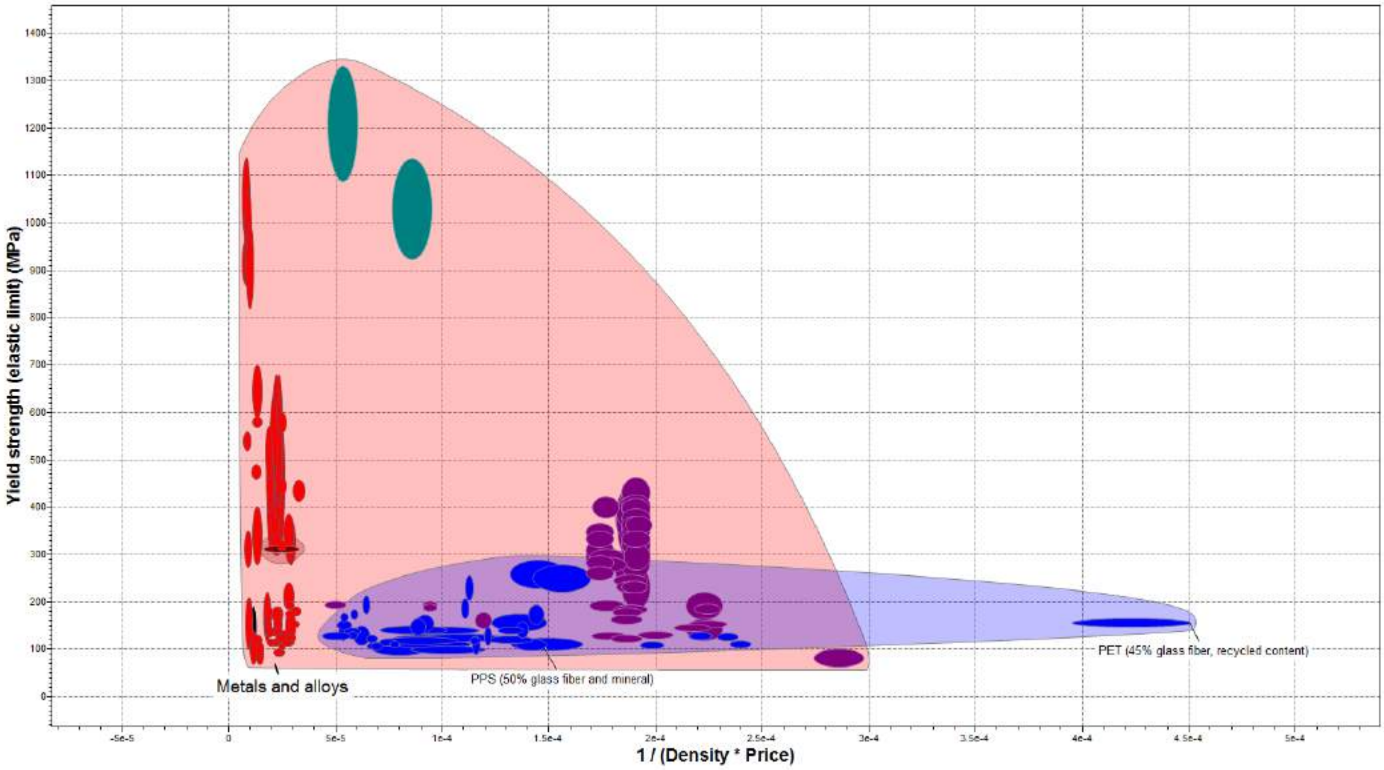
The following graphs are the iterations made in order to come up with a material choice. Four groups are to be determined. Blue are polymers, red are metals and alloys, and brown is a composite material. The iterations are done in the sequence the graphs are positioned. Within each graph the candidates among the plastics are pointed out. This way the actual choices made in the material selection are given more nuance. Whenever these graphs want to be reproduced, the limits of Appendix E can be used to generate them.

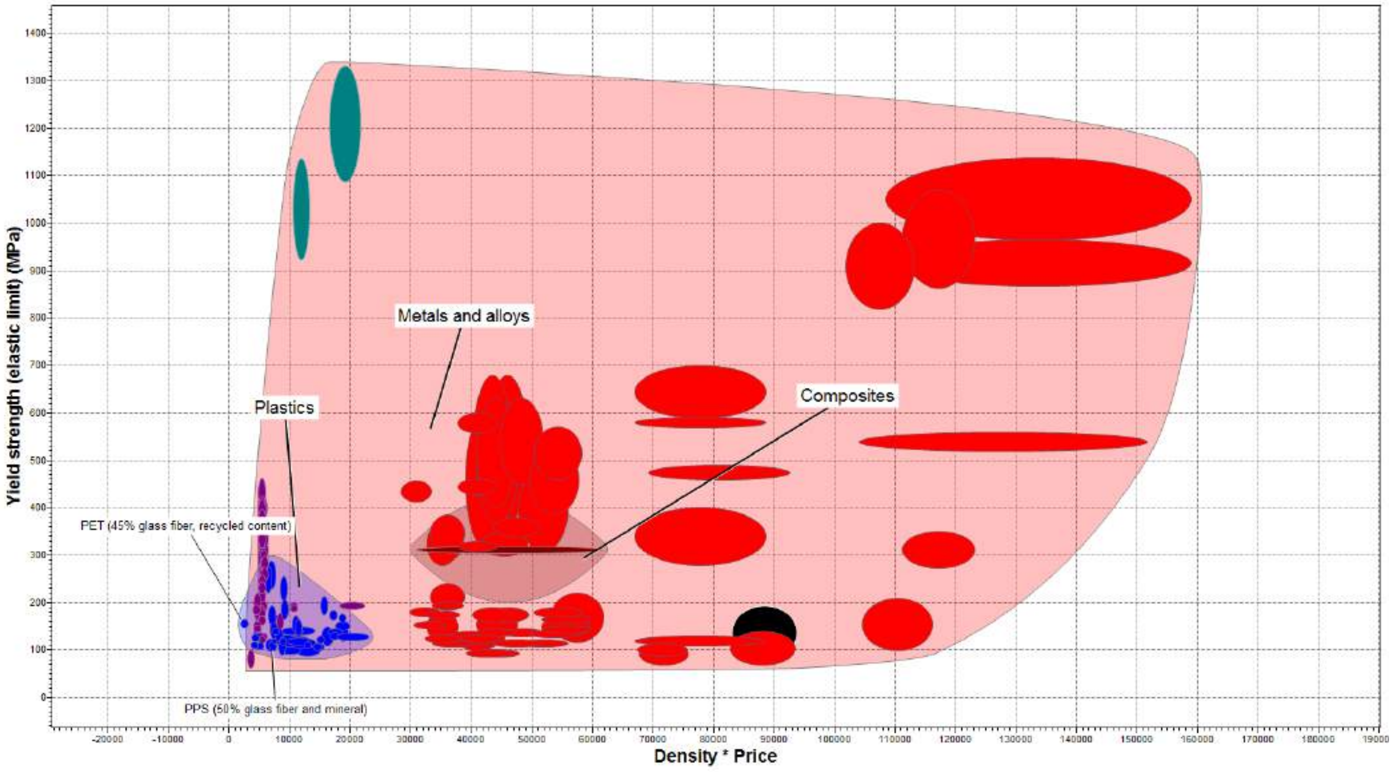


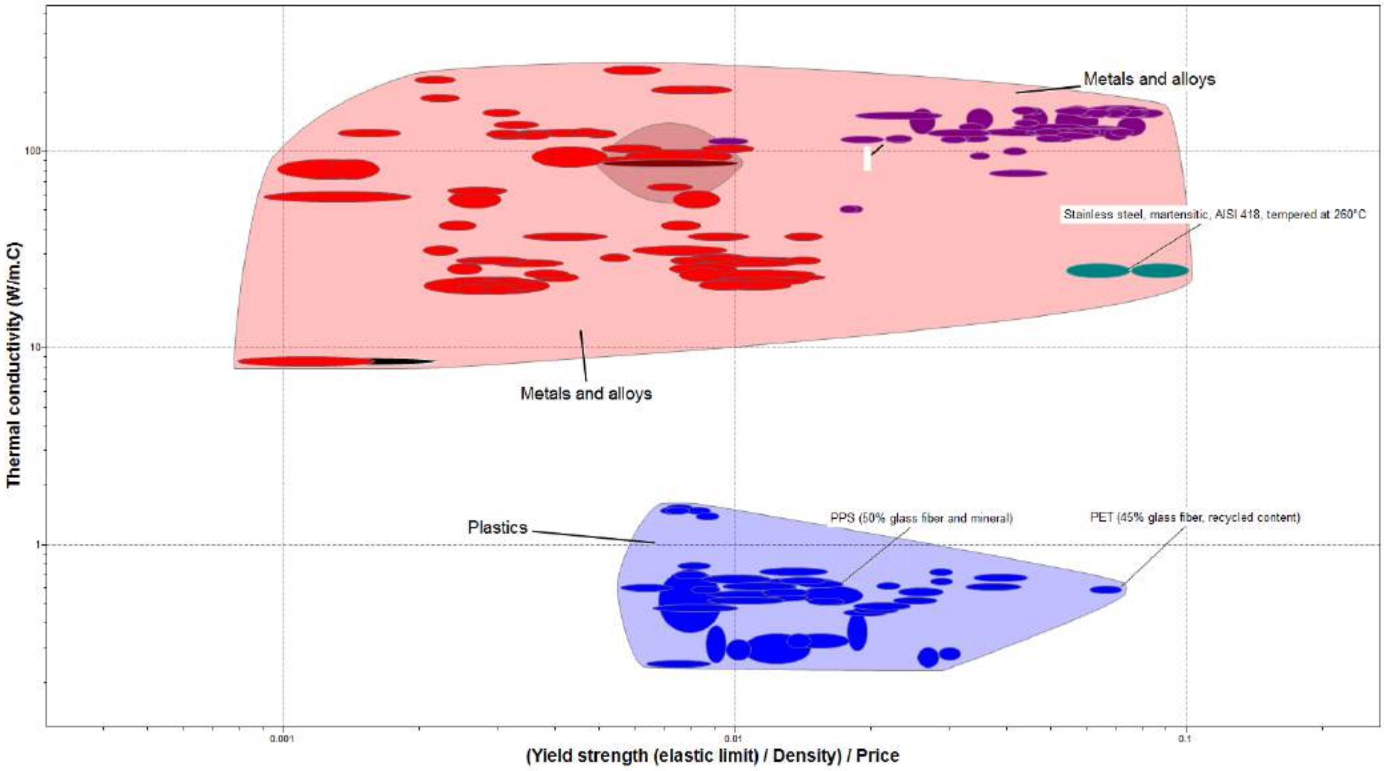


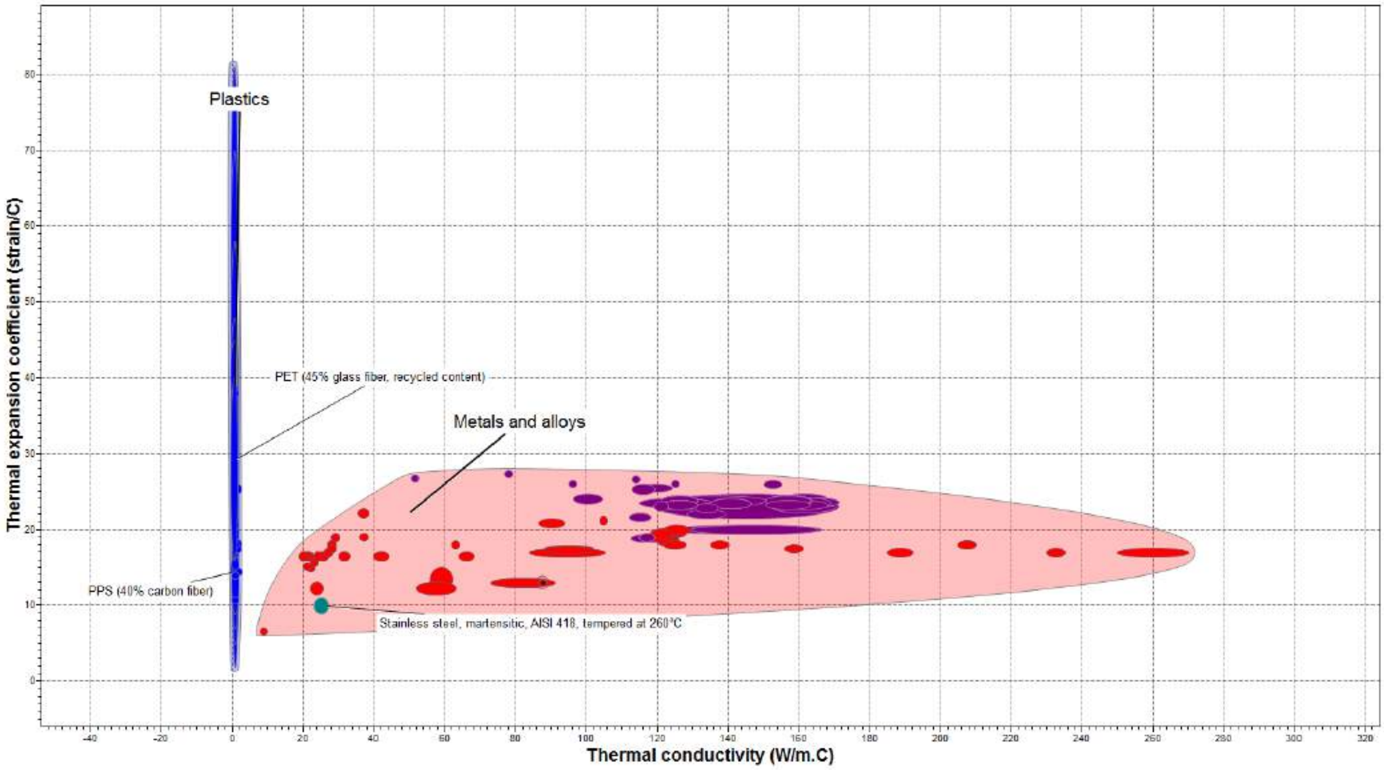

Thermal conductivity (W/m.C)
250
200
150
100
50
0
and alloys
Plastics
Stainless steel, martensitic, AISI 418, tempered at 260°C
PPS (50% glass fiber and mineral)
PET (45% glass fiber, recycled content)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
0.011
0.012
0.013
0.014
0.015
0.016
0.017
0.018
0.019
0.02
0.021
0.022
(Young's modulus / Density) / Price

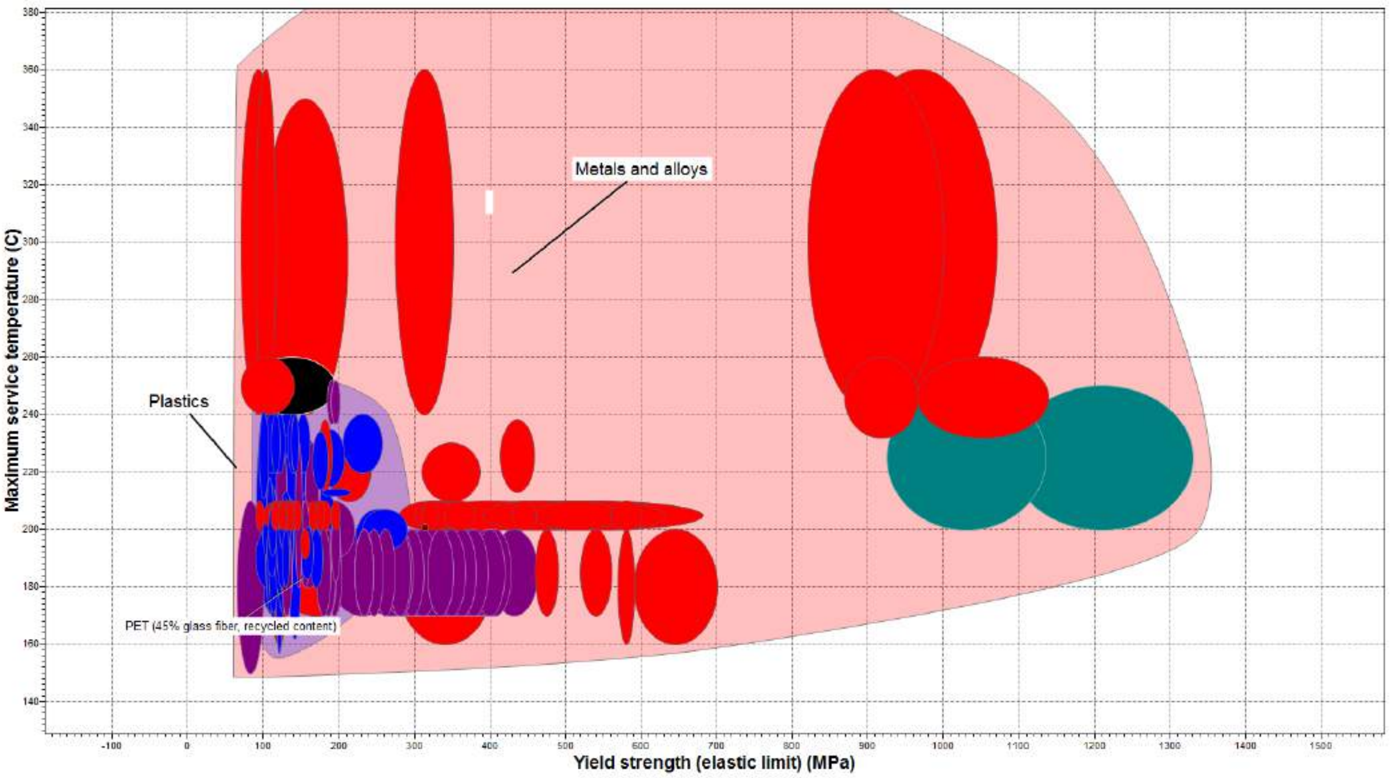

Young's modulus (GPa)
240
220
200
180
160
140
120
100
80
60
40
20
0
Composites
Zn-50%SiC(p)
Metals and alloys
PET (45% glass fiber, recycled content)
Plastics
PPS (50% glass fiber and mineral)
-5e-5
0
5e-5
1e-4
1.5e-4
2e-4
2.5e-4
3e-4
3.5e-4
4e-4
4.5e-4
5e-4
5.5e-4
6e-4
6.5e-4
7e-4
1 / (Density * Price)


Yield strength (elastic limit) (MPa)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-5e-5
0
5e-5
1e-4
1.5e-4
2e-4
2.5e-4
3e-4
3.5e-4
4e-4
4.5e-4
5e-4
1 / (Density * Price)
Metals and alloys
PPS (50% glass fiber and mineral)
PET (45% glass fiber, recycled content)


Yield strength (elastic limit) (MPa)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-20000
-10000
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
150000
160000
170000
180000
19000
Density * Price
Metals and alloys
Plastics
Composites
PET (45% glass fiber, recycled content)
PPS (50% glass fiber and mineral)


Metals and alloys
Stainless steel, martensitic, AISI 418, tempered at 260°C
Metals and alloys
Plastics
PPS (60% glass fiber and mineral)
PET (45% glass fiber, recycled content)
Thermal conductivity (W/m.C)
100
10
1
0.001
0.01
0.1
(Yield strength (elastic limit) / Density) / Price


Plastics
PET (45% glass fiber, recycled content)
Metals and alloys
PPS (40% carbon fiber)
Stainless steel, martensitic, AISI 418, tempered at 260°C
Thermal expansion coefficient (strain/C)
80
70
60
50
40
30
20
10
0
-40
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
Thermal conductivity (W/m.C)


Metals and alloys
Plastics
PET (45% glass fiber, recycled content)
Maximum service temperature (C)
380
360
340
320
300
280
260
240
220
200
180
160
140
-100
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Yield strength (elastic limit) (MPa)

Appendix G - Material Rosas

The overview is a collection of several materials which provides insight in standard materials their chemical resistance, whether it can hold certain temperatures and what manufacturing and joining techniques belong to the possibilities. The legend with the color coding is found in figure 4. The color code from the technical analysis (chemical and temperature resistance) is used to build the Material Rosas upon. Whenever a material is to be chosen for the AEC for instance, it can looked up in the legend table. It says what chemicals and temperature are involved for AEC. Next up, the Rosas can be looked into searching for a material which conforms with the color code and thus complies with the demands on chemical and temperature level. If interested some information is provided into what manufacturing or joining method is suitable to use. The Material Rosas is found on the next page.(figure 5)

- 🟫 Injection moulding
- 🟫 Extrusion
- 🟧 Blow moulding
- 🟧 Rotational moulding
- 🟥 Pressure sintering
- 🟪 Compression molding

- 🟦 Heat sealing
- 🟦 Laser welding
- 🟦 Ultrasonic welding
- 🟩 Friction welding
- 🟦 Adhesive bonding
- 🟦 Solvent bonding
- 🟥 Radio freqency welding
- 🟪 Hot plate welding

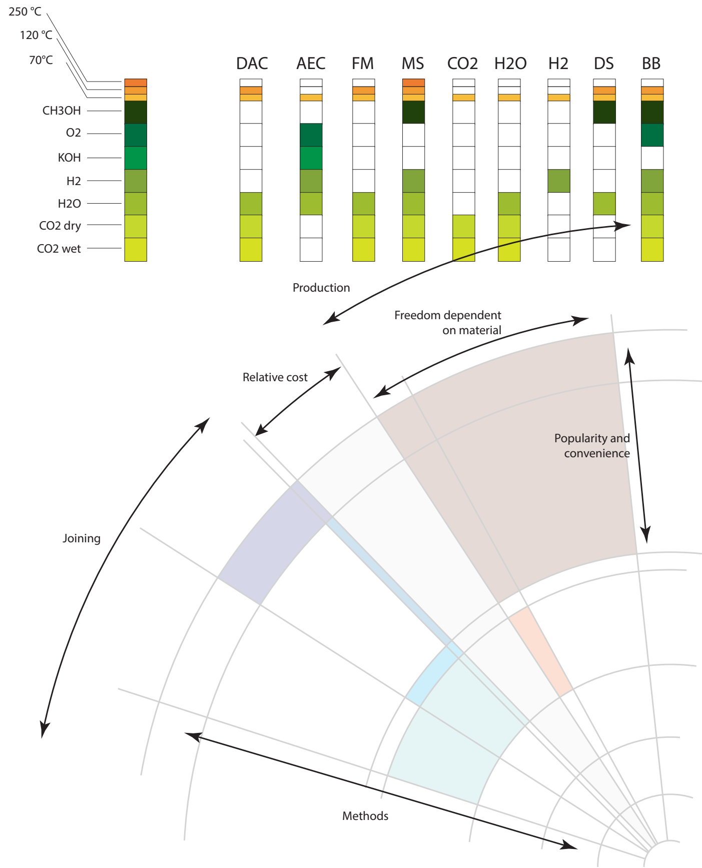
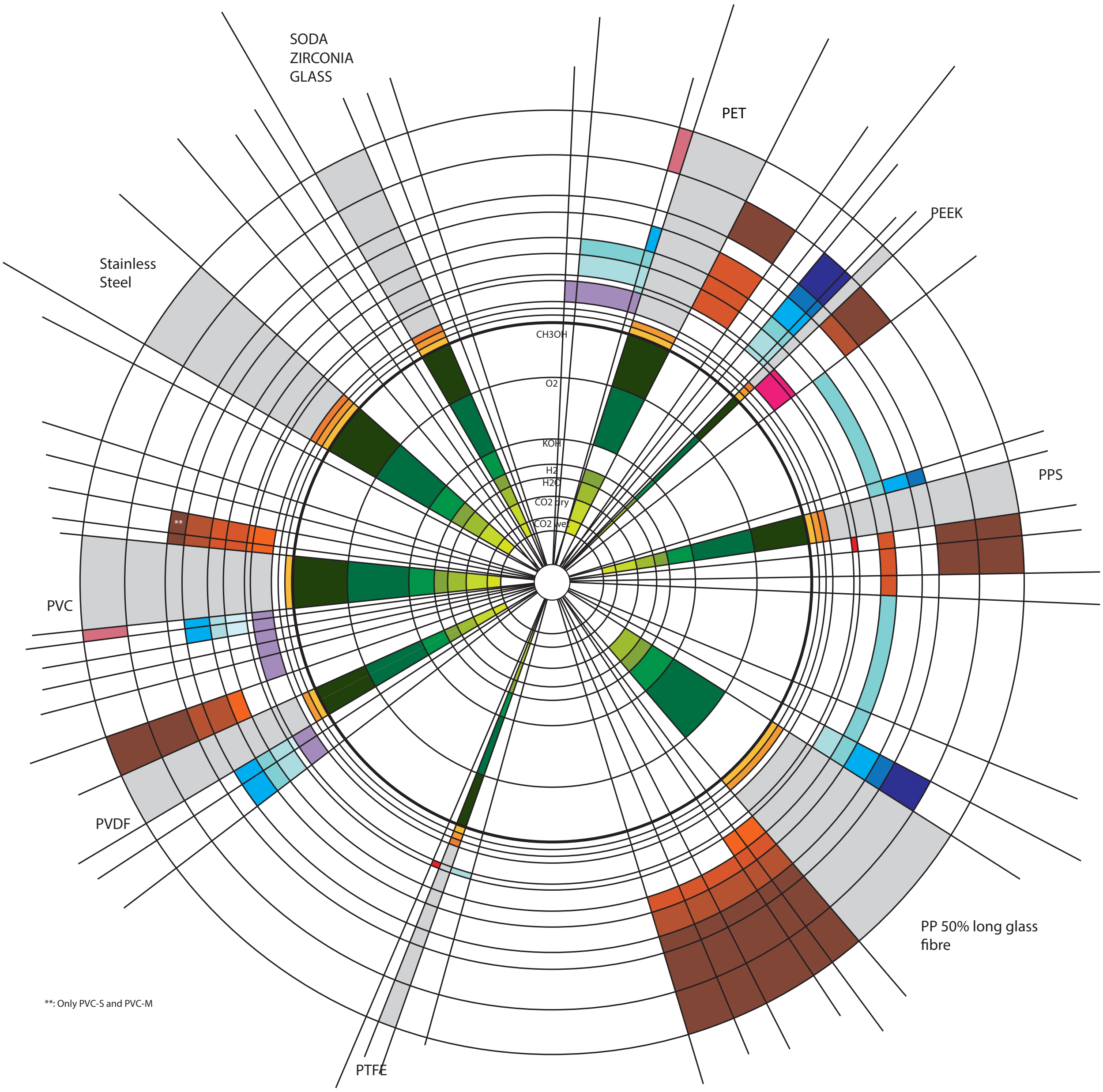


Figure 4. Legend to read the Material Rosas



**: Only PVC-S and PVC-M

Figure 5. Material Rosas, overview of the chemical and temperature resistance of common materials. Also manufacturing , cost and joining poroperties are taken into account

Appendix H - PET 45% GF

This appendix is about the common applications of PET 45% GF, references to design guides and methods of joining, and a datasheet of PET 45% GF (figure 7 on the next page). DuPont Engineering Polymers is found to be a supplier of the material where its commercial name is Rynite 545. All info gathered for input in calculations regarding processing cost and other calculations is based upon official datasheets of Dupont referred to below. Hereunder an overview of some interesting online PDF's elaborating on specific material properties, design, and joining techniques for PET 45% provided by DuPont.

1. **General Design Principles for DuPont Polymers**
http://www.dupont.com/content/dam/dupont/products-and-services/plastics-polymers-and-resins/thermoplastics/documents/General%20Design%20Principles/General%20Design%20Principles%20for%20Engineering%20Polymers.pdf

2. **Design information: Crastin PBT and Rynite PET**
http://www.dupont.com/content/dam/dupont/products-and-services/plastics-polymers-and-resins/thermoplastics/documents/Crastin/Crastin%20PBT%20and%20Rynite%20PET%20Design%20Info%20Module%20IV.pdf

3. **Rynite PET Thermoplastic Polyester Resin**
http://www8.basf.us/PLASTICSWEB/displayanyfile?id=0901a5e1801499d2

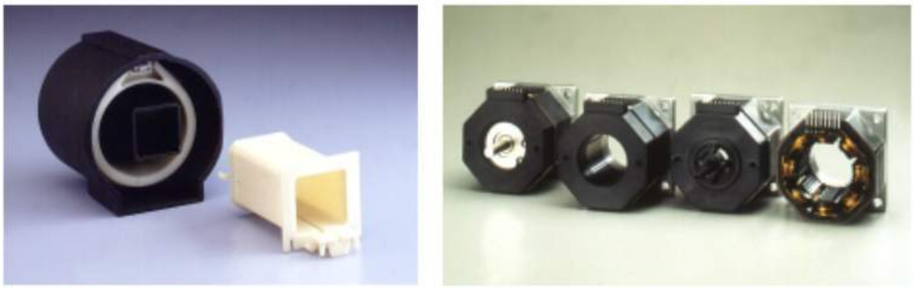
4. **Assembly Techniques - Category II Welding, Adhesive Bonding**
http://www.dupont.com/content/dam/dupont/products-and-services/plastics-polymers-and-resins/thermoplastics/documents/General%20Design%20Principles/General%20Design%20Principles%20for%20Assembly%20Techniques%20-%20Welding,%20Adhesive%20Bonding.pdf

Common Applications

Figure 6 provides an overview of some applications of PET45% GF. Other examples of usage are the following ones "…housings and covers, support brackets, pump parts, electrical sensor housings, motor parts, lamp sockets, terminal blocks, switches, bobbins, oven handles and control panels, small appliance housings, automotive support brackets, exterior components, headlamp retainers, ignition components, and luggage racks." (Dupont Engineering Polymers, 1995)

T-Roof Rail: Stiffness, strength and toughness, combined with good surface appearance.

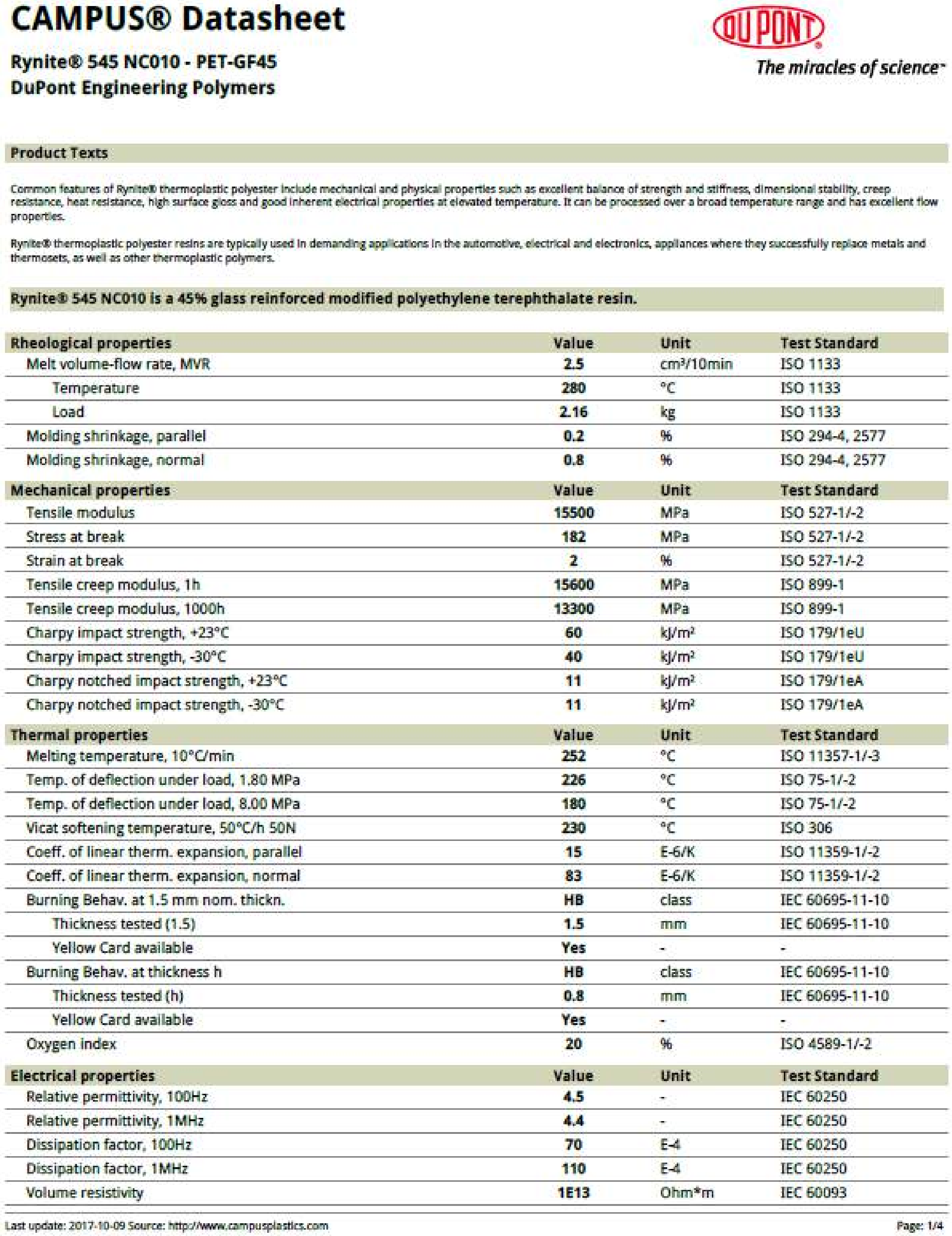
Oven Handle: High stiffness, low discoloration and distortion, and light color availability.



Coil Bobbin: Excellent dielectric properties, outstanding heat resistance, combined with lasting adhesion.

Encapsulated Motor Stator: All-in-one molded stator assembly, lower production time, and cooler operation.

Figure 6. Common application of PET 45% GF. From "DuPont Engineering Polymers", by DuPont, http://foremostplastic.com/wp-content/uploads/2015/04/DuPont-Module-IV-Rynite.pdf. Copyright [1995] by Dupont. Reprinted with permission.



CAMPUS® Datasheet

Rynite® 545 NC010 - PET-GF45
DuPont Engineering Polymers

Product Texts

Common features of Rynite® thermoplastic polyester include mechanical and physical properties such as excellent balance of strength and stiffness, dimensional stability, creep resistance, heat resistance, high surface gloss and good inherent electrical properties at elevated temperature. It can be processed over a broad temperature range and has excellent flow properties.

Rynite® thermoplastic polyester resins are typically used in demanding applications in the automotive, electrical and electronics, appliances where they successfully replace metals and thermosets, as well as other thermoplastic polymers.

Rynite® 545 NC010 is a 45% glass reinforced modified polyethylene terephthalate resin.

Rheological properties	Value	Unit	Test Standard
Melt volume-flow rate, MVR	**2.5**	cm^3/10min	ISO 1133
Temperature	**280**	°C	ISO 1133
Load	**2.16**	kg	ISO 1133
Molding shrinkage, parallel	**0.2**	%	ISO 294-4, 2577
Molding shrinkage, normal	**0.8**	%	ISO 294-4, 2577

Mechanical properties	Value	Unit	Test Standard
Tensile modulus	**15500**	MPa	ISO 527-1/-2
Stress at break	**182**	MPa	ISO 527-1/-2
Strain at break	**2**	%	ISO 527-1/-2
Tensile creep modulus, 1h	**15600**	MPa	ISO 899-1
Tensile creep modulus, 1000h	**13300**	MPa	ISO 899-1
Charpy impact strength, +23°C	**60**	kJ/m^2	ISO 179/1eU
Charpy impact strength, -30°C	**40**	kJ/m^2	ISO 179/1eU
Charpy notched impact strength, +23°C	**11**	kJ/m^2	ISO 179/1eA
Charpy notched impact strength, -30°C	**11**	kJ/m^2	ISO 179/1eA

Thermal properties	Value	Unit	Test Standard
Melting temperature, 10°C/min	**252**	°C	ISO 11357-1/-3
Temp. of deflection under load, 1.80 MPa	**226**	°C	ISO 75-1/-2
Temp. of deflection under load, 8.00 MPa	**180**	°C	ISO 75-1/-2
Vicat softening temperature, 50°C/h 50N	**230**	°C	ISO 306
Coeff. of linear therm. expansion, parallel	**15**	E-6/K	ISO 11359-1/-2
Coeff. of linear therm. expansion, normal	**83**	E-6/K	ISO 11359-1/-2
Burning Behav. at 1.5 mm nom. thickn.	**HB**	class	IEC 60695-11-10
Thickness tested (1.5)	**1.5**	mm	IEC 60695-11-10
Yellow Card available	**Yes**	-	-
Burning Behav. at thickness h	**HB**	class	IEC 60695-11-10
Thickness tested (h)	**0.8**	mm	IEC 60695-11-10
Yellow Card available	**Yes**	-	-
Oxygen index	**20**	%	ISO 4589-1/-2

Electrical properties	Value	Unit	Test Standard
Relative permittivity, 100Hz	**4.5**	-	IEC 60250
Relative permittivity, 1MHz	**4.4**	-	IEC 60250
Dissipation factor, 100Hz	**70**	E-4	IEC 60250
Dissipation factor, 1MHz	**110**	E-4	IEC 60250
Volume resistivity	**1E13**	Ohm*m	IEC 60093

Last update: 2017-10-09 Source: http://www.campusplastics.com

Page: 1/4

Figure 7. First page of a Datasheet of PET 45% GF. by Dupont, http://lookpolymers.com/pdf/DuPont-Performance-Polymers-Rynite-545-NC010-Polyethylene-Terephthalate-PET-nbspUnverified-Data.pdf. Copyright [1995] by Dupont. Reprinted with permission

Appendix I - Excel Sheet Parametric Model

The list below is an overview of the Excel sheet made. The codes in front of the calculations are linked to Appendix J. This appendix is meant to trace back the actual input in for the parametric model.

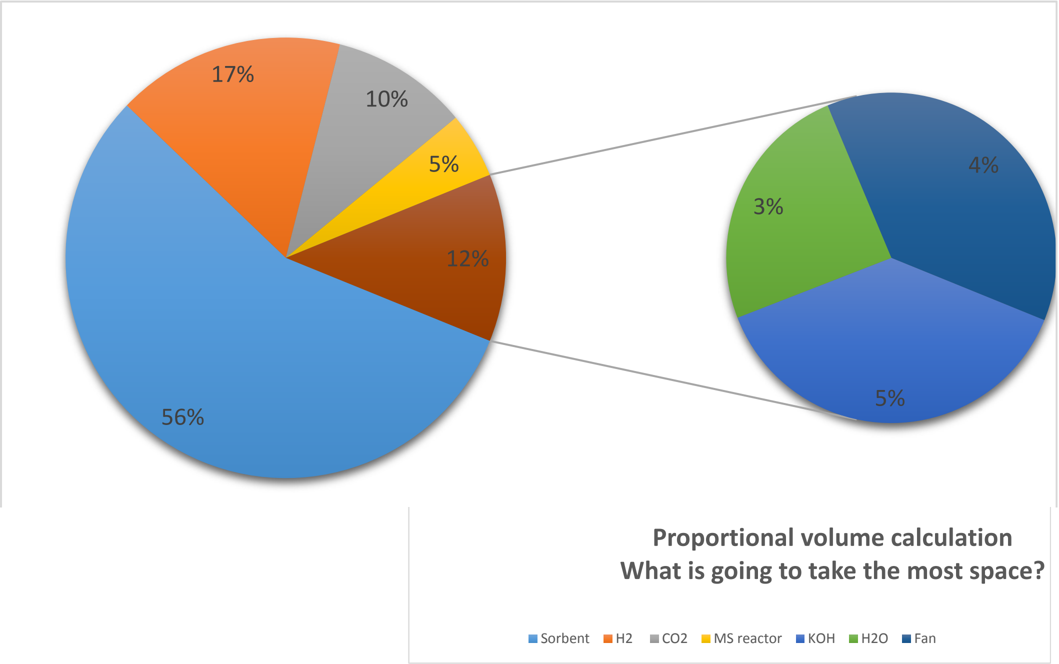
Parametric model in Excel

	DAC		
D1	Weight CO2 adsorbed per cycle by sorbent	0.044	kg CO2/cycle/kg sorbent
D2	Density sorbent	500	kg/m^3
D3	Duration cycle per chamber of adsorbtion and desorbtion	2	hour
D4	Amount of chambers	2	#
D5	Amount of cycles per day per chamber	4	#
D7	Amount of operational system hours per day	8	#
P4	Target weight MeoH per day	0.14	kg
S1	Target weight CO2 per day	0.1925	kg
	Target weight H2 per day	0.02625	kg
D6	Target void fraction	0.50	percentage
	Air molecular weight	28.97	g/mol
	Chemistry		
	C	12	g/mol
	H	1	g/mol
	O	16	g/mol
	Calculations weight CO2 needed per day		
P1	molecular weight H2	2	g/mol
P2	molecular weight MeOH	32	g/mol
P3	molecular weight CO2	44	g/mol
C1	weight of H2 needed per day to achieve target	0.02625	kg
S1	Target weight CO2 per day	0.1925	kg
P9	molecular weight H2O per day	18	g/mol
	Calculations sorbent volume needed		
S2	Amount of CO2 adsorbed per chamber per day(4cycles)	0.09625	kg
S3	Weight of sorbent per chamber	0.546875	kg/chamber
S4	Volume of sorbent per chamber	1.09375	l/chamber
S5	Total volume of Sorbent for both chambers	2.1875	liters
	Sidetrack: size sorbent chamber		
	length tube	0.001	meters
	radius tube	0.834447647	meters
	Fan volume	0.36	liters
P5	molecular weight of air	28.971	g/mol
P6	Weight of CO2 per m3 of air	0.000719587	kg/m^3
P7	efficiency CO2 capture from the air	0.25	percentage
P8	Target power of Fan	15.00	W

	Calculations dimension of sorbent chamber needed		
S6	Amount of kubic meters of air needed for target CO2 per day	267.5146645	m^3/day
S7	Times efficiency factor	1070.058658	m^3/day
S8	Target to be captured CO2 per sec	0.037154815	m^3/sec
	Tarrget flowrate in CFM		
S9	Presssure drop to overcome	403.7161858	Pa
	AEC		
A1	electrolysis efficiency	0.6	percentage
A2	stack voltage	2	Volts
A3	energy density of H2	120000000	Joule
A4	Amount of Cells	14	#
A5	Density KOH	2120	kg/m^3
	Calculations		
C1	Molecular weight of H2 needed to produce target MeOH	0.02625	kg/day
C2	Amount of power needed per day times efficiency coefficient	5250000	J/day
C3	Avarage Power	182.2916667	Watt
C4	Total surface of needed cells	364.5833333	square cm
C5	Total current	6.510416667	A
C6	Amount of H2O per day	0.23625	kg/day
C7	Width and height cel	5.103103631	cm
C8	Volume of KOH needed	0.364583333	liters
C9	Weight of KOH needed	0.772916667	kg
	MS		
R1	Void fraction CuZnO-Al2O3	0.5	percentage
R2	Density CuZnO-Al2O3	1775	kg/m^3
R3	Diameter tube	0.02	meters
R4	Length tube	0.15	meters
M1	Volume of chosen cilinder	4.71239E-05	m^3
M2	Weight of needed CuZnO-Al2O3	0.041822452	kg
M3	Volume of needed CUZnO-Al2O3	0.023561945	liters
	Tanks		
	Given		
B1	Amount of H2 needed per day	0.2624	l/g/day at 50 bar at 40 degrees Celsius
B2	Amount of buffer hours for H2	1	#
B3	Amount of H2 used per hour	5	g/hour
B4	Amount of CO2 needed per day	0.008638	l/g/day at 50 bar at 40 degrees Celsius
B5	Amount of buffer hours for CO2	2	#
B6	Amount of CO2 used per hour	45.5	g/hour
T1	Size H2 tank whole day	6.888	liters per day
T2	Size H2 tank for # hour	1.312	liters
T3	Size CO2 tank for whole day	1.662815	liters per day
T4	Size CO2 tank for # hours	0.786058	liters

Design change AEC: PET 45% preform(used for the foam model dimensions)

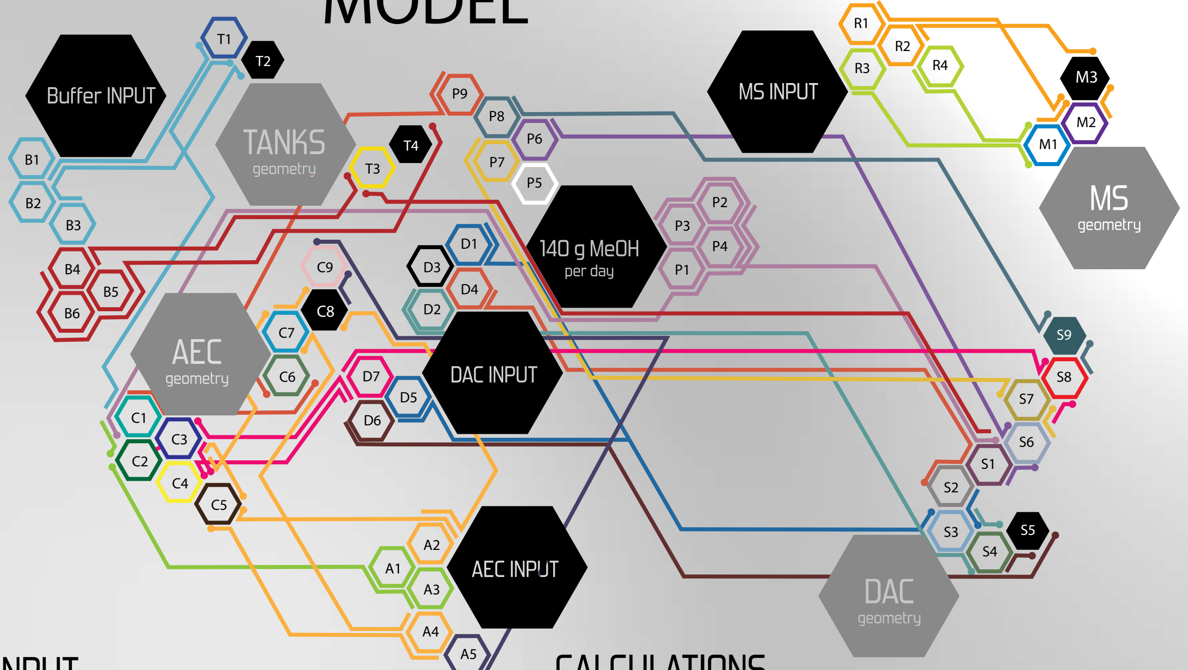
Required surface per tube	0.002604167	square m
Required spacing between membrane and tube	0.005	m
Total extra spacing middle	0.005	m
Required outer diameter tube	0.025	m
Required tube length+0.01m extra for	0.065262133	m
Total volume tube	3.20355E-05	cubic meter
Required liters of KOH to fill the 14 tubes	0.393809145	liters
Weight of KOH to fill the 14 tubes	0.834875387	kg
Total weight components(Sorbent, catalyst, H2O, CO2, H2, KOH)	2.321666667	kg
Total volume components (Sorbent, H2, CO2, KOH, H2O, catalyst)	6.861203278	liters



Appendix J - Calculations Parametric Model

Every code mentioned is linked back to the values mentioned in Appendix I. This overview is meant to provide insight in the calculations made to come up with the obtained volumes.

PARAMETRIC MODEL



INPUT

D1 Weight CO2 adsorbed per cycle by sorbent [kg CO2/cycle/kg sorbent]
D2 Density sorbent [kg/m3]
D3 Duration cycle per chamber of adsorbtion and desorbtion [hour]
D4 Amount of chambers [#]
D5 Amount of cycles per day per chamber [#]
D6 Target void fraction [%]
D7 Amount of operational system hours per day [#]

P1 Molecular weight H2 [g/mol]
P2 Molecular weight MeOH [g/mol]
P3 Molecular weight CO2 [g/mol]
P4 Target weight MeOH per day [kg/day]
P5 Molecular weight of air [g/mol]
P6 Weight of CO2 per m3 of air [kg/m3]
P7 Efficiency CO2 capture from the air [%]
P8 Target power fan [W]
P9 Molecular weight H2O [g/mol]

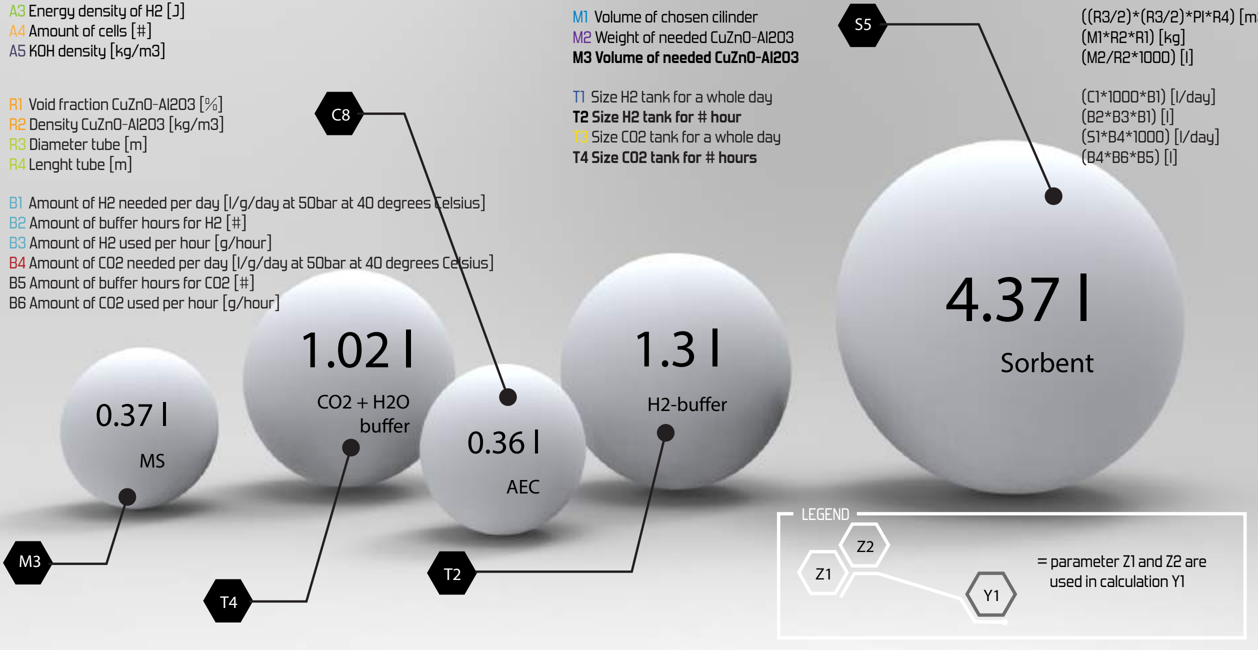
A1 Electrolysis efficiency [%]
A2 Stack voltage [V]
A3 Energy density of H2 [J]
A4 Amount of cells [#]
A5 KOH density [kg/m3]

R1 Void fraction CuZnO-Al2O3 [%]
R2 Density CuZnO-Al2O3 [kg/m3]
R3 Diameter tube [m]
R4 Lenght tube [m]

B1 Amount of H2 needed per day [l/g/day at 50bar at 40 degrees Celsius]
B2 Amount of buffer hours for H2 [#]
B3 Amount of H2 used per hour [g/hour]
B4 Amount of CO2 needed per day [l/g/day at 50bar at 40 degrees Celsius]
B5 Amount of buffer hours for CO2 [#]
B6 Amount of CO2 used per hour [g/hour]

CALCULATIONS

S1 Target weight CO2 per day	(P4*P3)/P2)[kg]
S2 Amount of CO2 adsorbed per chamber per day (4cycles)	(S1/D4) [kg]
S3 Weight of sorbent per chamber	(S2/(D1*D5) [kg/chamber]
S4 Volume of sorbent per chamber	(S3*D3/1000) [l/chamber]
S5 Total volume of Sorbent for both chambers	(S4*D6*2) [liters]
S6 Amount of m3 of air needed for CO2 target per day	(S1/P6)[m3/day]
S7 Amount of m3 of air needed for CO2 target per day times efficiency factor	(S6*(1/P7)[m3/day]
S8 Target to be captured CO2 per sec	(S7/D7)/3600) [m3/sec]
S9 Pressure drop to overcome (	(P8/S8) [Pa]
C1 Weight of H2 needed per day to achieve target	((P4*P1*3)/P2)*Z)[kg]
C2 Amount of power needed pr day times efficiency coëfficient	(C1*A3*(1/A1) [J/day]
C3 Average power	(C2/(3600*D7) [W]
C4 Total surface needed cells	(C2/(D7*3600))/0.5 [cm2]
C5 Total current	(C3/(A4*A2)) [A]
C6 Amount of H2O per day needed	(P9/2)*C1) [kg/day]
C7 Width and height cel	(root(C4/A4) [cm]
C8 Volume of KOH needed	(A2*C7*C7)/1000 [l]
C9 Weight of KOH needed	(A5*(C8/1000)) [kg]
M1 Volume of chosen cilinder	((R3/2)*(R3/2)*PI*R4) [m3]
M2 Weight of needed CuZnO-Al2O3	(M1*R2*R1) [kg]
M3 Volume of needed CuZnO-Al2O3	(M2/R2*1000) [l]
T1 Size H2 tank for a whole day	(C1*1000*B1) [l/day]
T2 Size H2 tank for # hour	(B2*B3*B1) [l]
T3 Size CO2 tank for a whole day	(S1*B4*1000) [l/day]
T4 Size CO2 tank for # hours	(B4*B6*B5) [l]



= parameter Z1 and Z2 are used in calculation Y1

Appendix K - Effect of Efficiencies on Volumes

Parameter overview
What is the effect of a change in efficiencies with regard to the subsystems and the microplant on their volumes? Figure 8 below communicates an overview of the parameters which have been taken into account for the research. The research is done based upon applying a factor to the initial input. For instance, if the daily target is to be doubled, the 1 must changed to 2 on the first line, which will consequently effect the volume and cost of several subsystems.

In addition to the Excel file listed in Appendix I, research is done in what the effect is on the volumes whenever the input or efficiencies must be altered due to design changes. Figure 8 provides an overview of the parameters to change. Within this appendix the effect on the DAC, AEC and buffers have been listed. They provide an overview of the results for changing input-values. It can be concluded that the larges volumes, namely the DAC and buffers are the most sensitive to changes. The outcome of the research is used as “background requirement” in the architectural layout of the micro-plant design. Which means that the volumes sensitive to changes, are easily to be adjusted in the designed architecture.

Parameter sensitivity analysis

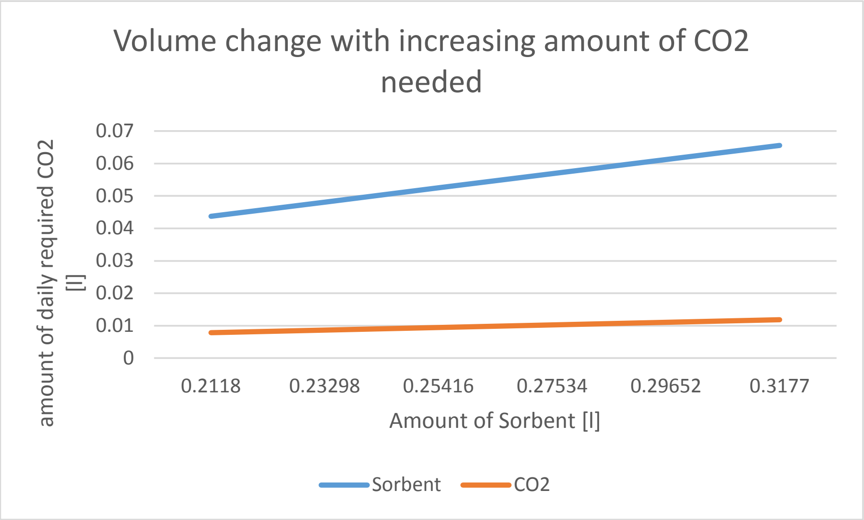
FACTOR_Target weight MeOH per day (0.1925kg)	1	volume and cost
FACTOR_Target weight H2 per day (0.02625kg)	1	volume and cost
FACTOR_Target weight CO2 per day (0.2118kg)	1	volume and cost
FACTOR_Target available fan power (15watt)	1	cost
FACTOR_Target electrolyser efficiency (60%)	0.6	volume and cost
FACTOR_Amount of catalyst MS (0.0418kg)	1	volume and cost
FACTOR_Amount of buffer hours for H2 (1 hour)	1	volume and cost
FACTOR_Amount of buffer hours for CO2 (2 hours)	1	volume and cost

Figure 8. Parameters to tweak

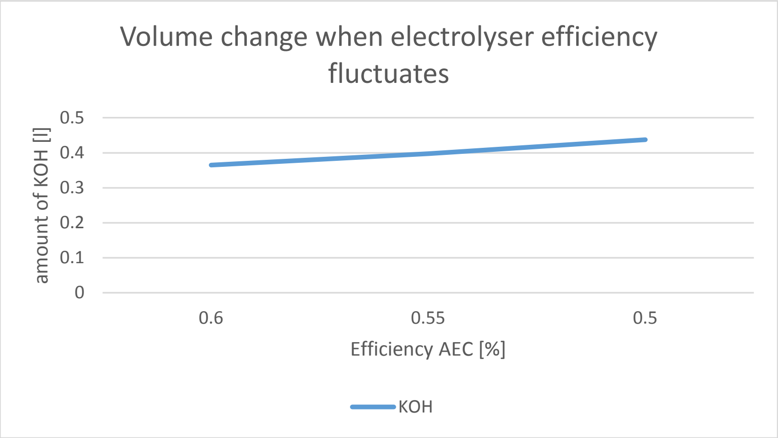
DAC Volume change

This table alters the target amount of CO2 to capture on a daily basis. The table communicates how the amount of Sorbent and required CO2 buffer volume increase with increasing daily CO2 target.

	0.2118	0.23298	0.25416	0.27534	0.29652	0.3177
Sorbent	4.375	4.8125	5.25	5.6875	6.125	6.5625
CO2	0.786058	0.864664	0.94327	1.021875	1.100481	1.179087

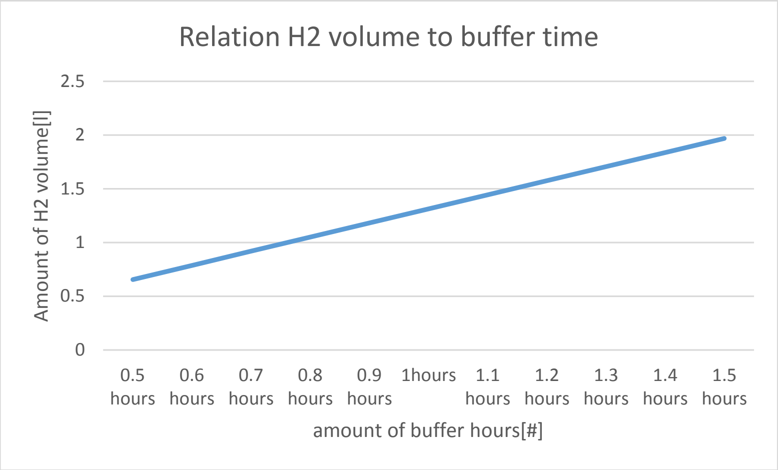


AEC efficiency	0.6	0.55	0.5
KOH	0.364583	0.39773	0.4375



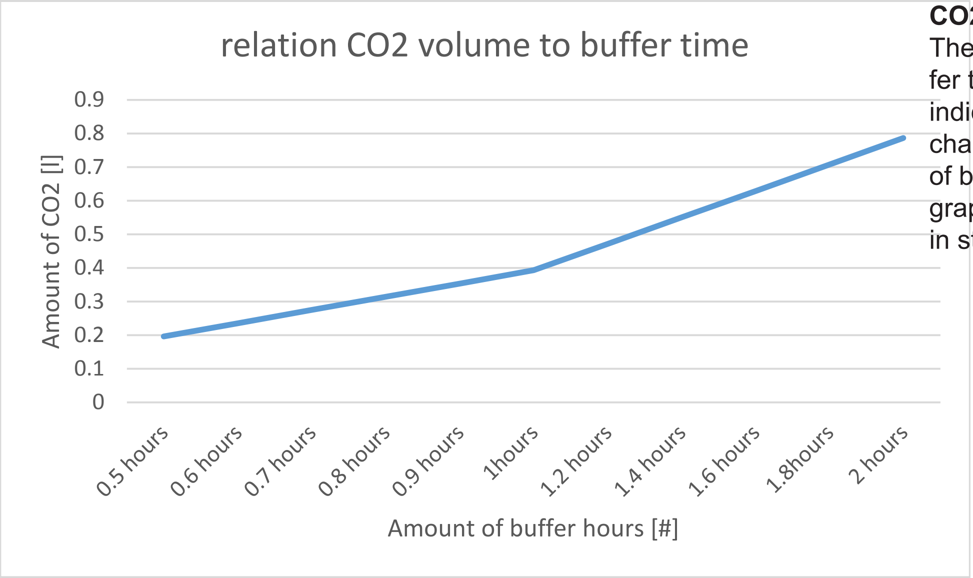
AEC Volume change
The AEC sub-system is calculated at an efficiency of 55%. The more efficient the less KOH is required. This volume only changes 0.05l per 5% of changing efficiency as seen in the graph.

Change in H2 buffer	0.5hrs	0.6hrs	0.7hrs	0.8hrs	0.9hrs	1hrs	1.1hrs	1.2hrs	1.3hrs	1.4hrs	1.5hrs
H2	0.656	0.786	0.918	1.049	1.180	1.312	1.443	1.574	1.705	1.836	1.968



H2-buffer volume change
The H2-buffer system is calculated at a buffer time of 1 hour. The graph clearly indicates how the estimated volume changes over a changing amount of buffer hours.

Change in CO2 buffer	0.5hrs	0.6hrs	0.7hrs	0.8hrs	0.9hrs	1hrs	1.1hrs	1.2hrs	1.3hrs	1.4hrs	1.5hrs
CO2	0.1965	0.235	0.275	0.314	0.353	0.393	0.471	0.550	0.628	0.707	0.786



CO2-buffer volume change
The CO2-buffer is calculated at a buffer time of 2 hours. The graph clearly indicates how the estimated volume changes over a changing amount of buffer hours. the last part of the graph is steaper due to an increase in step size.

Appendix L - Mount to Solar Racking System

Introduction
The analysis phase revealed that the FM, AEC and MS system are orientation sensitive. Which means a decision is to be made of how the backbone is going to be mounted at the solar panel whilst respecting the sub-system orientations. This appendix provides a brief overview of the considerations and research done with regard to the mount of the backbone to the solar panel.

Method and workflow
Through collages and exploring sketching the possibilities with regard to possible micro-plant mounts have been explored. At first, the solar racking system market along with similar mounting systems for products have been looked into. Based upon the findings, a decision is made to base the architectural lay-out of the micro-plant upon.

Results
Prior to research the possibilities, challenges have been defined with regard to the backbone orientation. These help to focus and steer the search towards an optimal solution. Hereunder an overview.

- Minimize additional complexity
- Minimize cost
- Maximize robustness
- Maximize reachability

Based on image research and literature, the conclusion can be made that the solar racking system market is enormous. Principally, four different kinds of racking systems are defined. Carports and canopies, trackers(keep track of the sun), ground mounts and roofs (flat and slope). Where ZEF focusses on the ground mounts. Within the ground mount family, two variations exist. The single post and double post option. Each of them positioned at different angles. Figure 9 provides an overview.

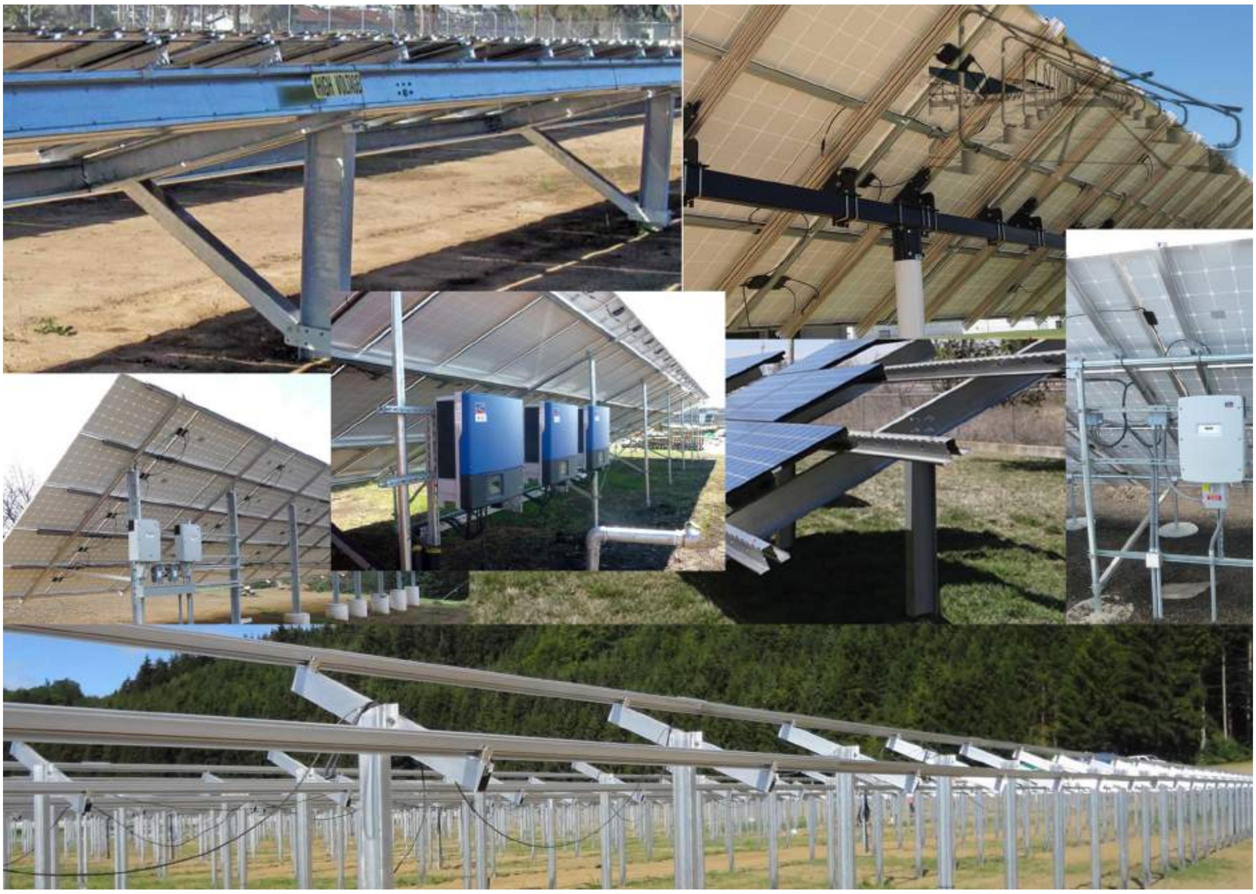


Figure 9. Solar Racking System Market Analysis (Focussed upon single and double post configurations)

Common denominator

In order to provide some grip in the search towards possibilities, common denominators have been searched for the design-options available regarding ground mounts for 300W solar panels.
In total all ground mounts have three things in common. All of them have a vertical, horizontal and inclined oriented profile to mount objects upon. Also, all of them are light weight extrusion profiles either made from aluminum or stainless steel. Each of these denominators have advantages and disadvantages. Figure 10 provides an overview of the Pro’s and Con’s regarding mount.

Parameters with regard to mounting

- Complexity

As little as possible additional complexity as a result of the mount is desired. Having the micro-plant installed at the back of the solar panel, is not favored. This would increase the complexity of the backbone due to the need for stair-shaped form. Required for the mount and to provide a secured vertical placement of the MS, AEC and FM.

- Longitudinal Support

The longitudinal support offers opportunities with regard to possible support of the racking system for the mount of the backbone. This is necessary to secure a safe and rigid connection between micro-plant and racking system.

- Mounting

The ease of mounting. For instance, the ground is to avoided at all cost since it is always different.

As a result it is decided to focus the orientation phase on a vertical mounting profile. With the notion, the product is not to touch the ground under any circumstances.

Figure 11 provides an overview of inspirational products hanging in an alternative way.

Ideation

The ideation is started in figure 12 and continues in figure 13 on the next page. Several positions have through quick sketches been explored. Step D within the analysis is the stair-shaped option which increases the complexity of the backbone as described in the parameters se ction on the previous page. For all the iterations, there are serious problems to be named.
Eventually, based upon limited time and no breakthroughs this problem is set aside along with some recommendations for further research.

Discussion

Ideation has been done, in exploring the possibilities. Unfortunately no solution has been found dealing with all requirements in the reserved time. Therefore the best solution in terms of minimizing design complexity has been chosen. This way a first look can be taken into the design of the backbone ignoring the additional difficulties of a multi-plane backbone. The choice is made to go with the horizontal placement to the solar racking system. This without a doubt will causes robustness/fatigue problems with regard to the fixture mechanism. Also weight distribution and vulnerability to wind could be points of attention. Therefore at a later stage in the design process the orientation certainly requires a stiffness/FEM analysis where internal and external factors(specific wind data/vibrations caused by FM and doors) need to be taken into account. At a later stage it is recommended to look again into a vertical mount, similar to power inverters already mounted to solar racking systems. Furthermore, it is recommended to research whether the weight of the backbone can be carried by the standard profiles. Are these capable to carry this amount of extra weight at ay location?

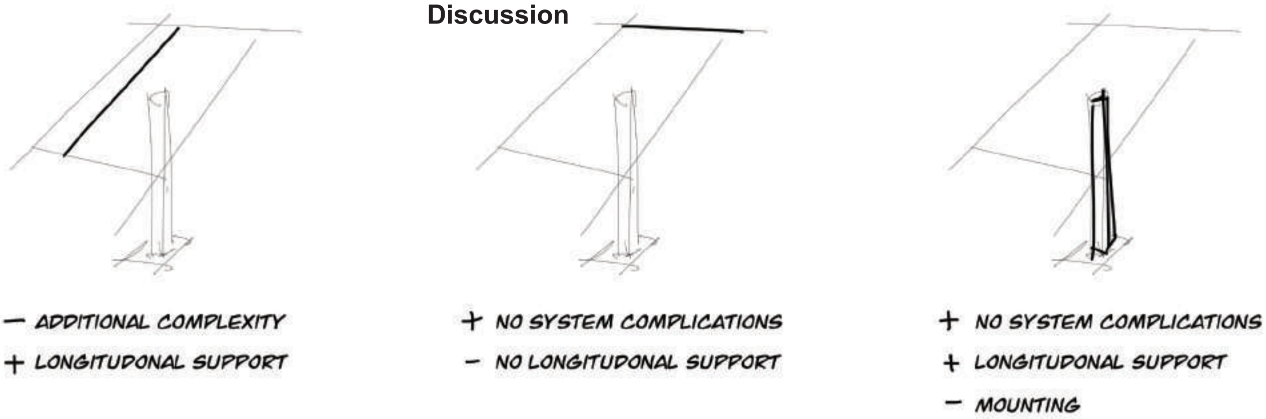


Figure 10. Common denominator for the single and ouble post racking system

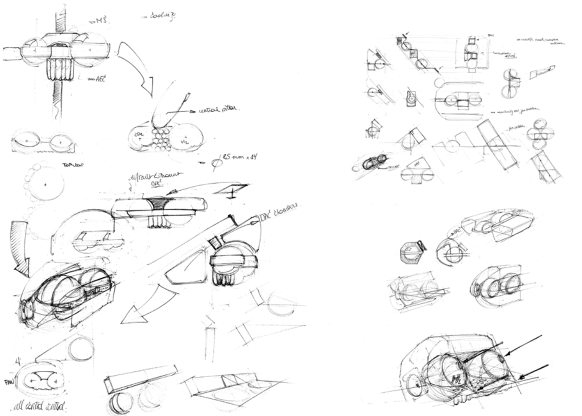


Figure 13. Ideation mounts solar racking system part 2

Figure 11. Inspirational products regarding mounts

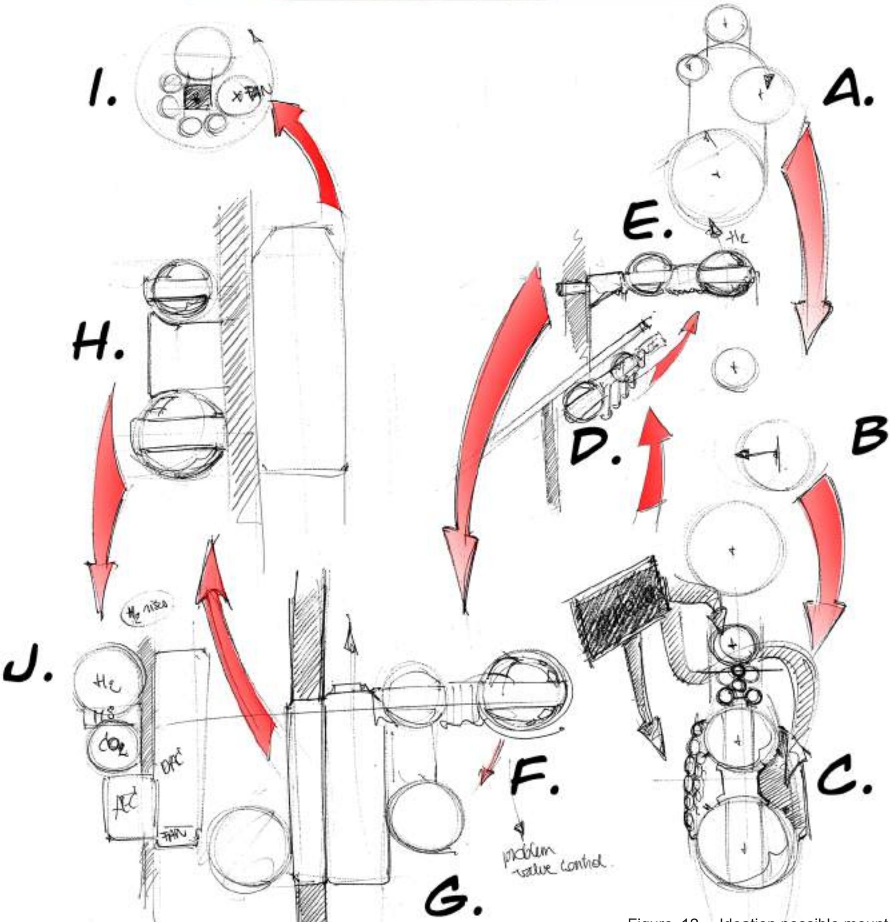


Figure 12. Ideation possible mounts to solar racking systems part 1

Conclusion

For this thesis it is concluded to neglect the vertical orientation where needed. No reliable solutions to the challenges defined at the start of this research have been found. The consequence is a simplification of the backbone design and thus final feasibility study. The expected effect is difficult to quantify. For sure, the mount is a serious challenge to spend more time upon.

Appendix M - Fish Trap Model

This appendix zooms in at what subsystem is positioned where.
Figure 14 provides an overview of every object used in the Fish Trap Model. The objects have been chosen based upon their similarity with the obtained volumes and geometries retrieved from the parametric model.

DAC chambers - 4.3 liter
Fan - 0.36 liter
H2-buffer - 1.3 liter
H2O-buffer - 0.23 liter
CO2-buffer - 0.78 liter
AEC - 0.36 liter
MS - 0.37 liter

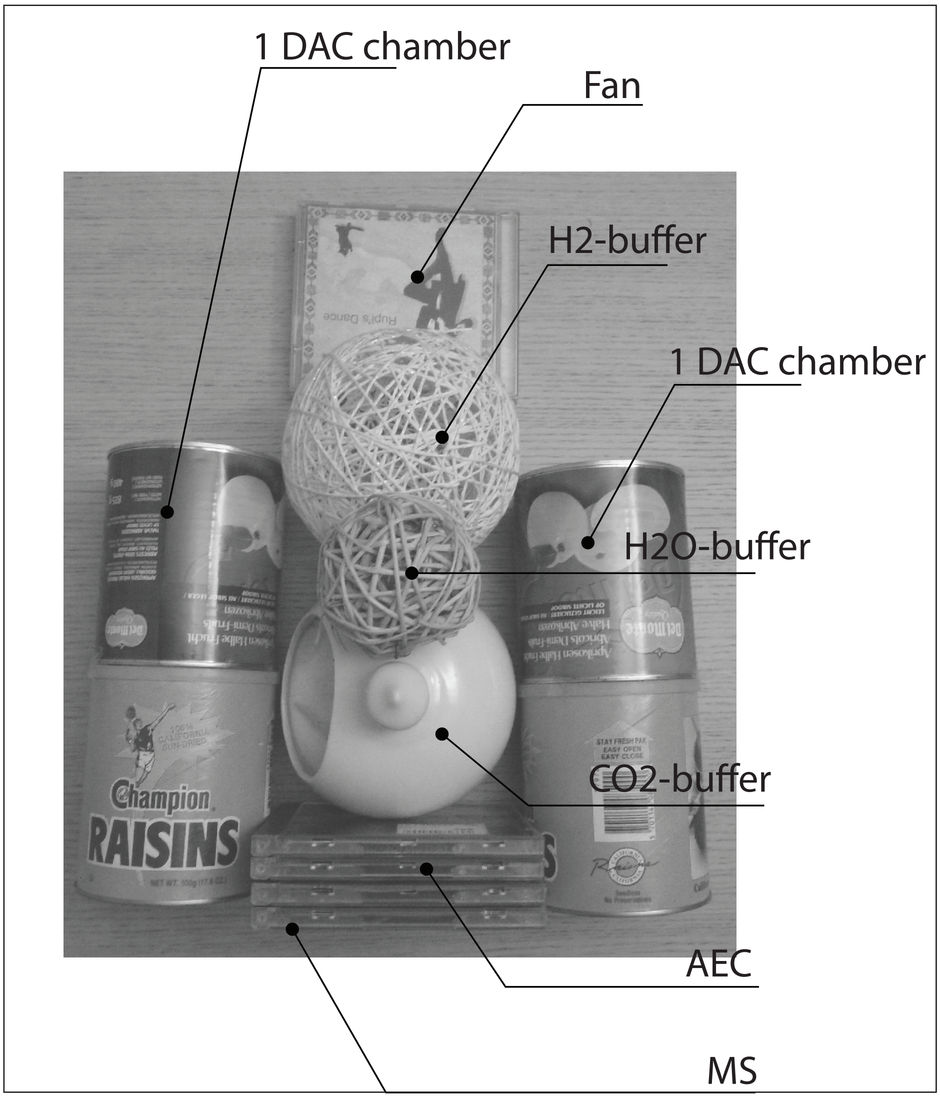


Figure 14. Representation of subsystems by items used for the FIsh-Trap-Model

Appendix N - The Backbone Concept

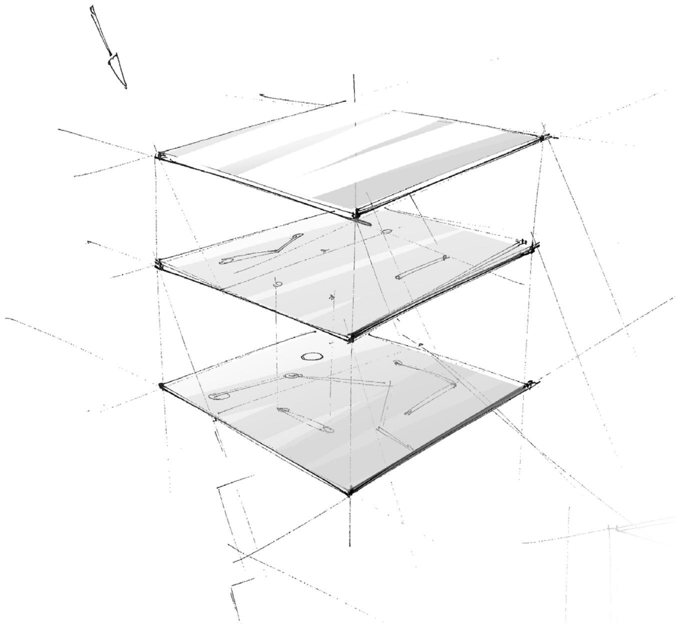


Figure 15. Three-plated backbone design allows for component integration

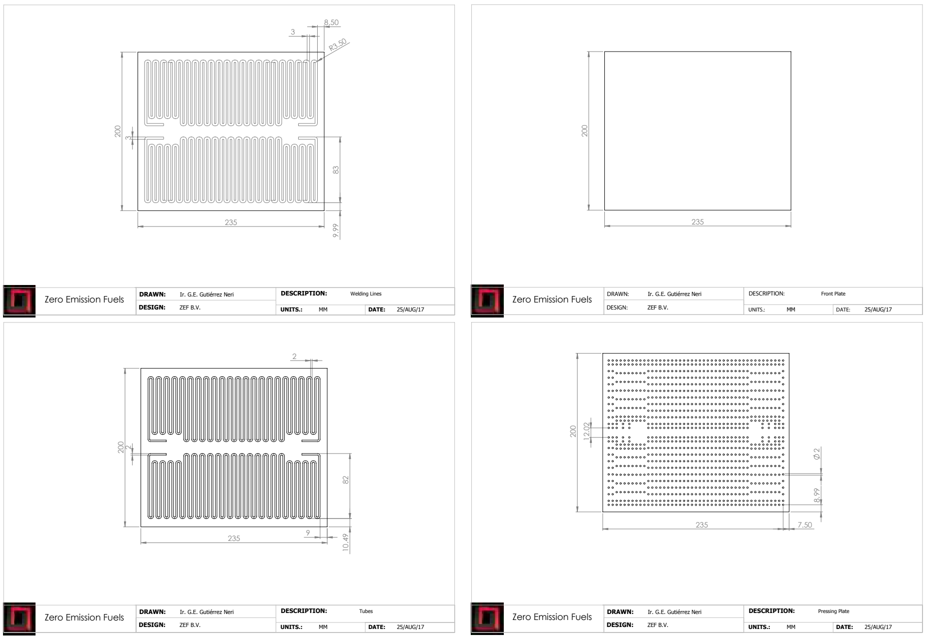


Figure 16. Technical drawings send for laser welding the first backbone prototype

Introduction
This appendix is about the three-plated concept. It will entail the research done prior to this thesis. Also it will provide a brief explanation of the opportunities and will be tested upon the list of requirements composed along the process of this thesis. Based upon the result, a decision will be made whether the concept is interesting to base the detail design phase upon.

Context: The need for backbone
Is there a low cost solution to be found which is able to reduce the amount of parts (canals and support of components and subsystems) which is also suitable for mass manufacturing? Thus, the backbone is about integration. Via integration applied on design for mass manufacturing the amount of parts and thus cost per final product is lowered significantly.

The Concept: Team ZEF0
Three-plates, stacked on top of each other enable for all piping work integration. Whatever orientation a canal requires, even crossing other canals, they can be implemented in three plates. The middle plate only serves to allow for canals crossing each other. Figure 15 provides an overview. First tests laser welding three stainless steel milled plates on top of each other resulted in a failure. Warpage as a result of too thin material and high temperatures caused the material to warp. (technical drawings found in figure 16. Nevertheless, the concept is not worthless. A different material choice might solve the problem and allow for more complex design with respect to component integration.

Figure 17. Backbone prototype of Team ZEF1, CNC-milled POM, bolts mounting the plates to each other miss in the photograph taken

PER_B_GEN_R_04	The product forms a sturdy attachment point for all unit operations & sensors
PER_B_GEN_R_06	The product is to be mounted on a solar racking system
PER_B_DAC_R_03	The product needs to contain 2 sorbent chambers
PER_B_DAC_R_05	The sorbent has total volume of 4.38liters (incl. void fraction of 0.5)
PER_B_DAC_R_06	The material needs to be CO2 resistant
PER_B_DAC_R_07	The material needs to withstand a temperature range of ((-20)-120 degrees Celsius).
PER_B_DAC_R_08	The product needs to withstand an under pressure of 0.1bar up to 1 bar
PER_B_DAC_R_11	The material needs to be 100% H2O resistant
PER_B_AEC_W/R_01	The material needs to be 100% KOH resistant
PER_B_AEC_R_04	The product needs to withstand a pressure of 52 bar
PER_B_AEC_R_07	The product needs to bear a total amount of KOH which equals a weight of 0.77 kg
PER_B_AEC_R_08	The product needs to contain 0.364l of KOH
PER_B_AEC_R_09	The material needs to be 100% O2 resistant
PER_B_AEC_R_10	The material needs to be 100% H2O resistant
PER_B_AEC_R_11	The material needs to be 100% H2 resistant
PER_B_DS_R_01	The material needs to withstand a temperature range between 70-100 degrees Celsius
PER_B_DS_R_02	The material needs to be 100% CH3OH resistant
PER_B_DS_R_03	The product needs to contain a wick
PER_B_DS_R_04	The material needs to be 100% H2O resistant
PER_B_TA_R_01	The product needs to contain a H2 tank with a volume of 1.312 liters (1 hour buffer)
PER_B_TA_R_02	The product needs to contain a CO2 tank with a volume of 0.786 liters (2 hour buffer)
PER_B_TA_R_03	The product needs to contain a H2O tank with a volume of 0.236 liters
ENV_B_GEN_R_01	The product must protect the subsystems from external influences
ENV_B_GEN_R_02	The product must not pollute the environment with any of its contents
ENV_B_GEN_R_03	The product must be leak tight
ENV_B_GEN_R_05	The product needs to be UV resistant
ENV_B_GEN_R_06	The product must be placed in the desert (sunbelt region)
LIS_B_GEN_R_01	The product must function 20 years every day for approximately 7hours
MAI_B_GEN_R_01	The product must enable the user to access the DAC subsystem for the sorbent
MAI_B_GEN_R_02	The product must enable the user to access the AEC subsystem replaceing its contents
MAI_B_GEN_W_01	The product should enable the user to replace the electronical parts (fans, sensors, heater, actuator,...)
TPC_B_GEN_R_08	The IC accounts for 2.5 % of the total production cost or 3.5 euros
QUA_B_GEN_R_01	The product must be produced at an amount of 40.000 pcs or more
QUA_B_GEN_R_02	The product must be produced in batches.
SaW_B_GEN_R_01	The product must weigh not more than 7kg
REL_B_GEN_R_01	The product must not fail on pressure and temperature requirements
SAF_B_GEN_R_01	The product must protect the user from hot regions
SAF_B_GEN_R_02	The product must be self-explanatory with regard to danger (hot surface, toxic material, etc)
SAF_B_GEN_R_03	The product must have use cues for carriage
SAF_B_GEN_R_04	The product must have use cues for refill of content/hot swap of sub parts
SAF_B_GEN_W_03	The product must enable hot swap on the solar rack

Figure 18. Test whether the three-plated concept conforms with the List of requirements for the backbone composed along this project and is suited to research further in the detail design phase. (Complete list is found in appendix B). Light grey is not relevant for detail design, or is excluded from this project, or has been dealt with in a former chapter. Red is problematic, green is possible.

The concept: Team ZEF1

In parallel to my thesis, ZEF 1 developed a three-plated first working backbone prototype made out of POM via CNC-milling. The plates have been bolted to each other and sealed with laser cut rubber. This first backbone prototype involves the control of multiple valves by one servo motor. However the design involves the use of expensive, heavy Swagelok connections. Still lots of other components require research for integration. Figure 17 provides an overview.

The concept: This Thesis

The concept is promising. The three-plate concept allows for crossing canals and thus a minimization of backbone surface. A first working prototype by team ZEF 1 proved to work. However many other functionalities require integration. Therefore, the concept is worth researching whether a cheap backbone design can be presented for the integration of the essential backbone functionalities. Before preceding to the detail phase the concept is tested upon the list of requirements. Figure 18 provides an overview.

The three-plated concept is found in line with the requirements. Also, during the process no other concept or idea came even close to integrate components in a cheap way. Therefore it is decided to continue research the opportunities of the three-plated concept.

Appendix O - Framework Detail Design

Detail Design for CNC-milling

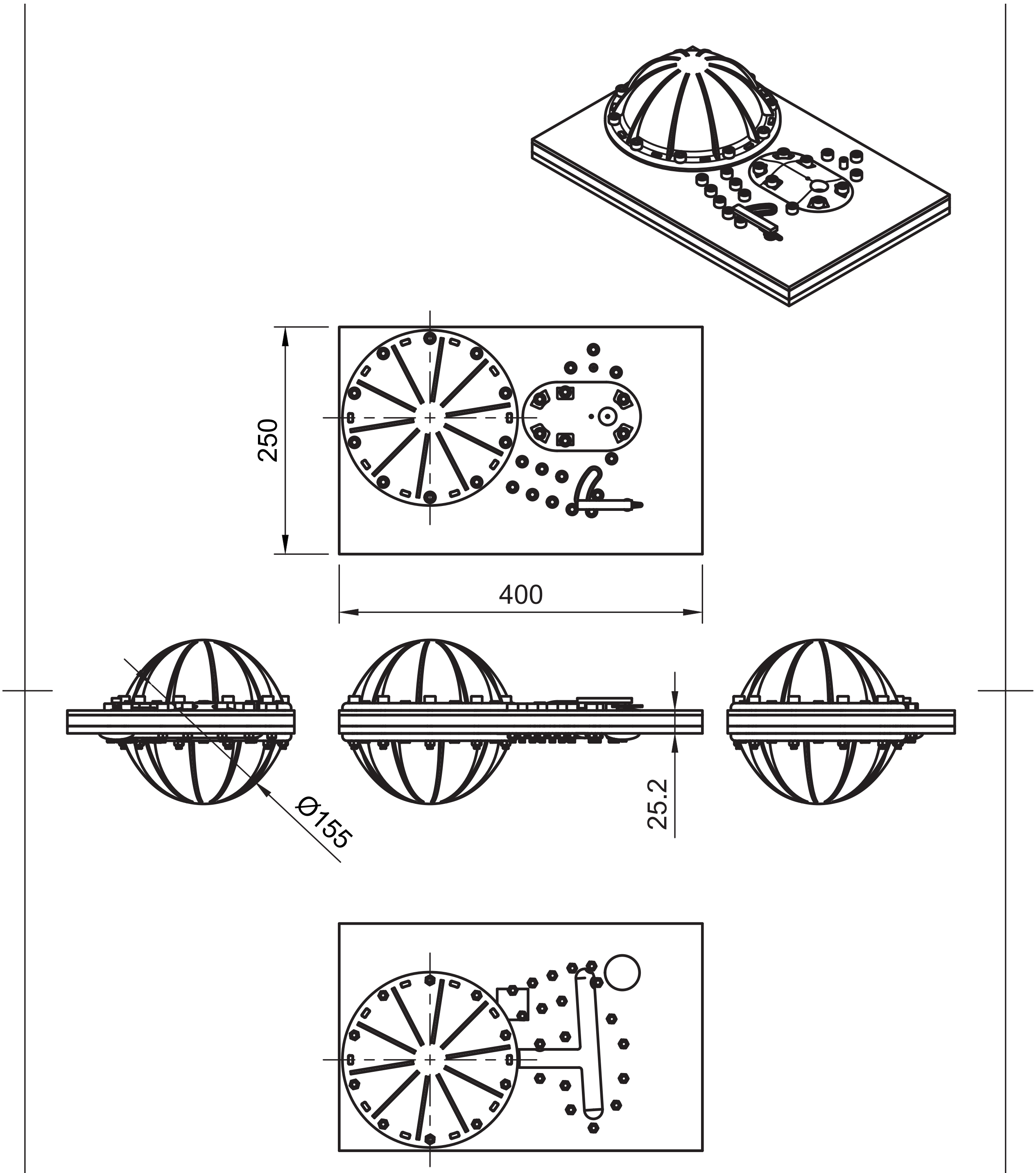
The backbone sample has been designed for Computer Numerical Controlled (CNC)-milling. This method enables relatively cheap prototyping and is afterwards easily translated towards injection molding. Notwithstanding, design for CNC-milling heavily influences the detail design phase. Likewise, another material has been chosen than PET 45% GF. Polyvinyl chloride (PVC) is found to be well suited for CNC milling. It is cheaper than Polyoxymethylene (POM) and has good overall chemical resistivity and mechanical properties. Important to realize is that CNC-milling causes the design to be dependent by available material dimensions of the supplier and machine restrictions.

Another option with regard to material choice for prototyping is anodized aluminum. This material has Excellent mechanical properties and does not conduct heat. However, problems are expected with regard to a difference in thermal stresses between the coating and the aluminum, causing it to crack at temperatures above 80 degrees. (Edwards, 1997) Also, the coating might cause troubles in the assembly of the backbone plate with regard to joining and sealing. Nonetheless, warpage as a result of CNC-milling large thin PVC objects is expected as well. However, radial seal design (explained in detail Design) should cancel out any warpage.

Flow Design Backbone Sample

The aspects valuable to test are given priority and thus positioned more upfront the flow design of the backbone sample. For this reason the solenoid is positioned before the buffer, minimizing risk with regard to leakage.

Appendix P - Technical Documentation



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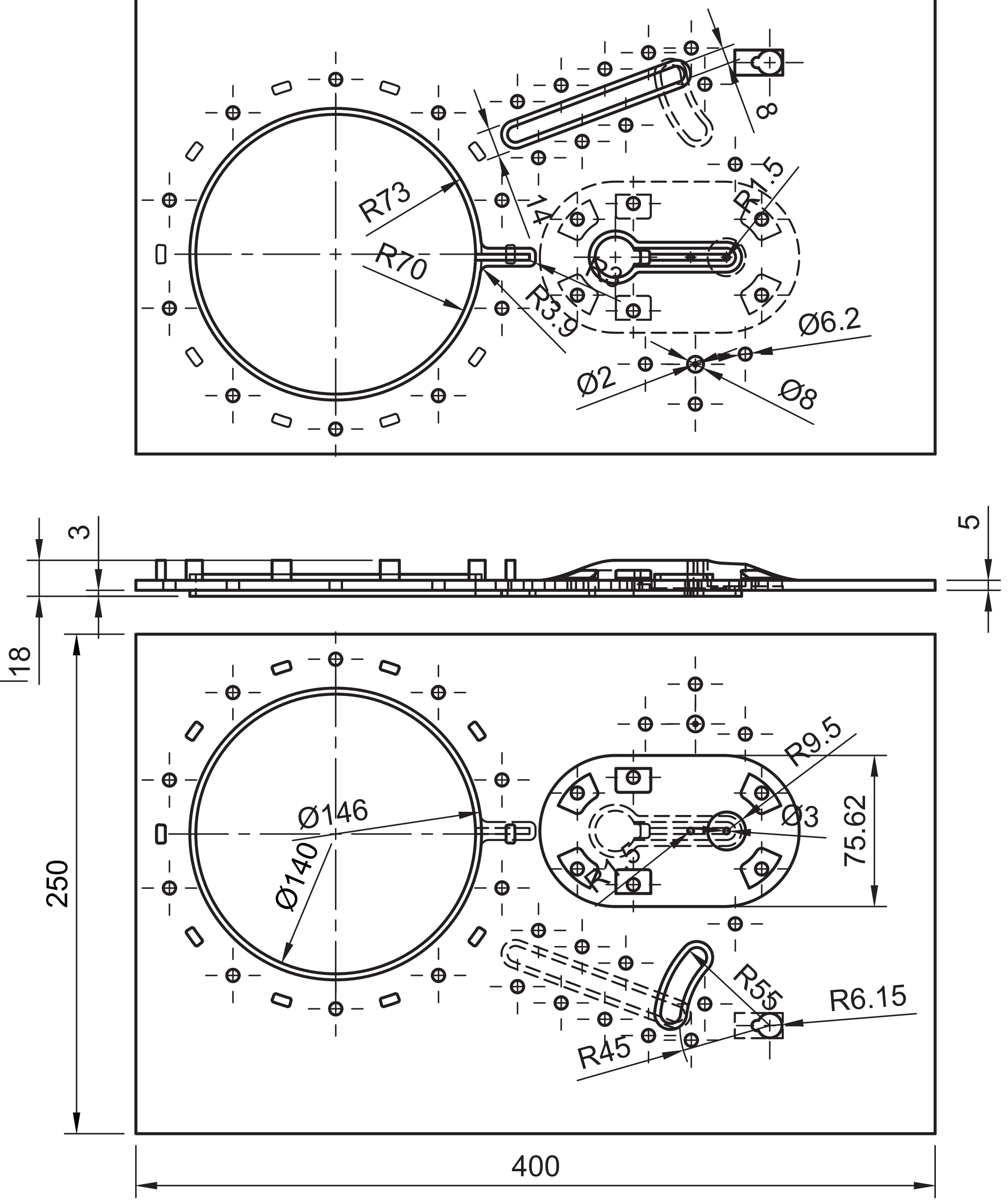

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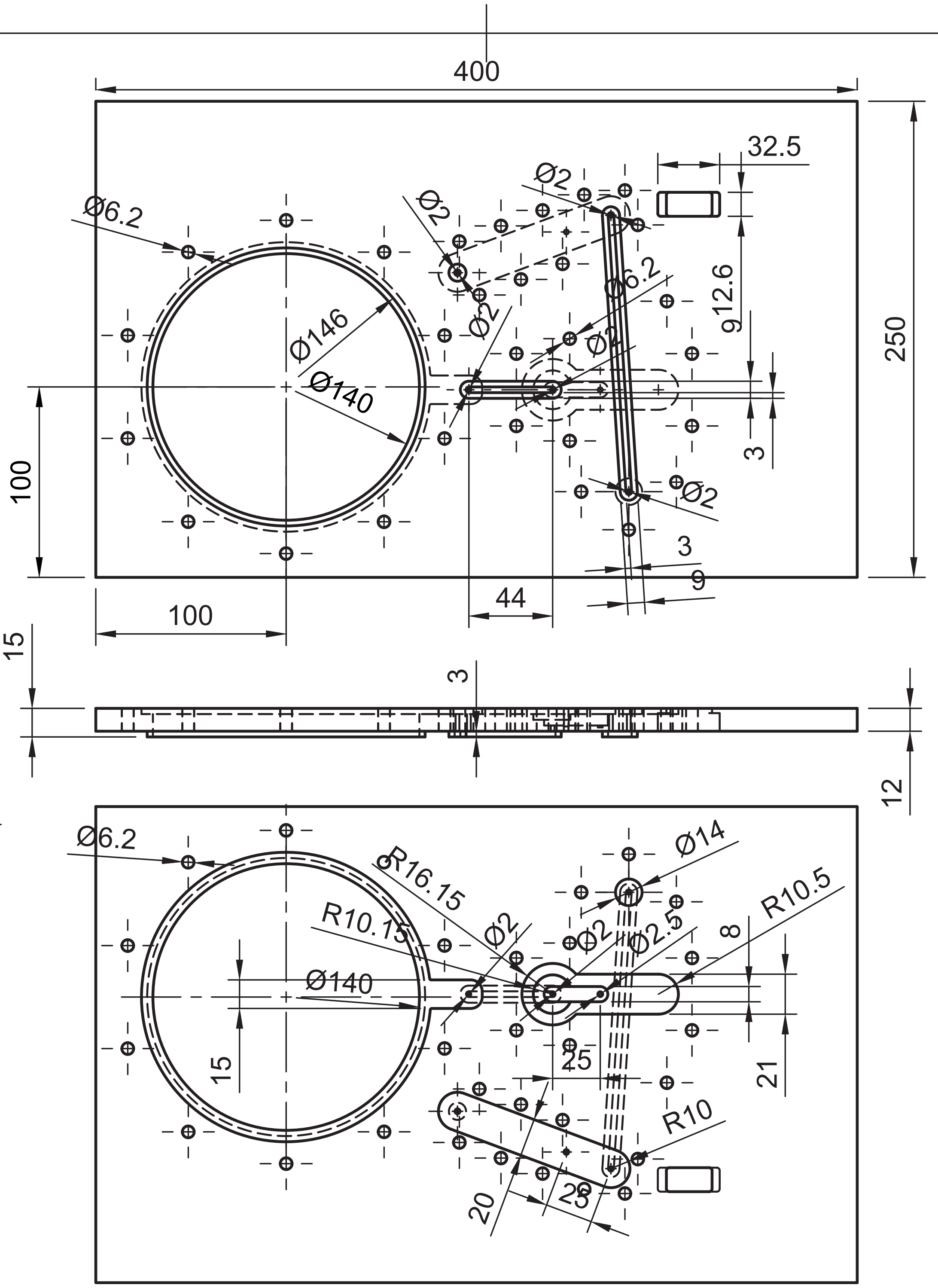

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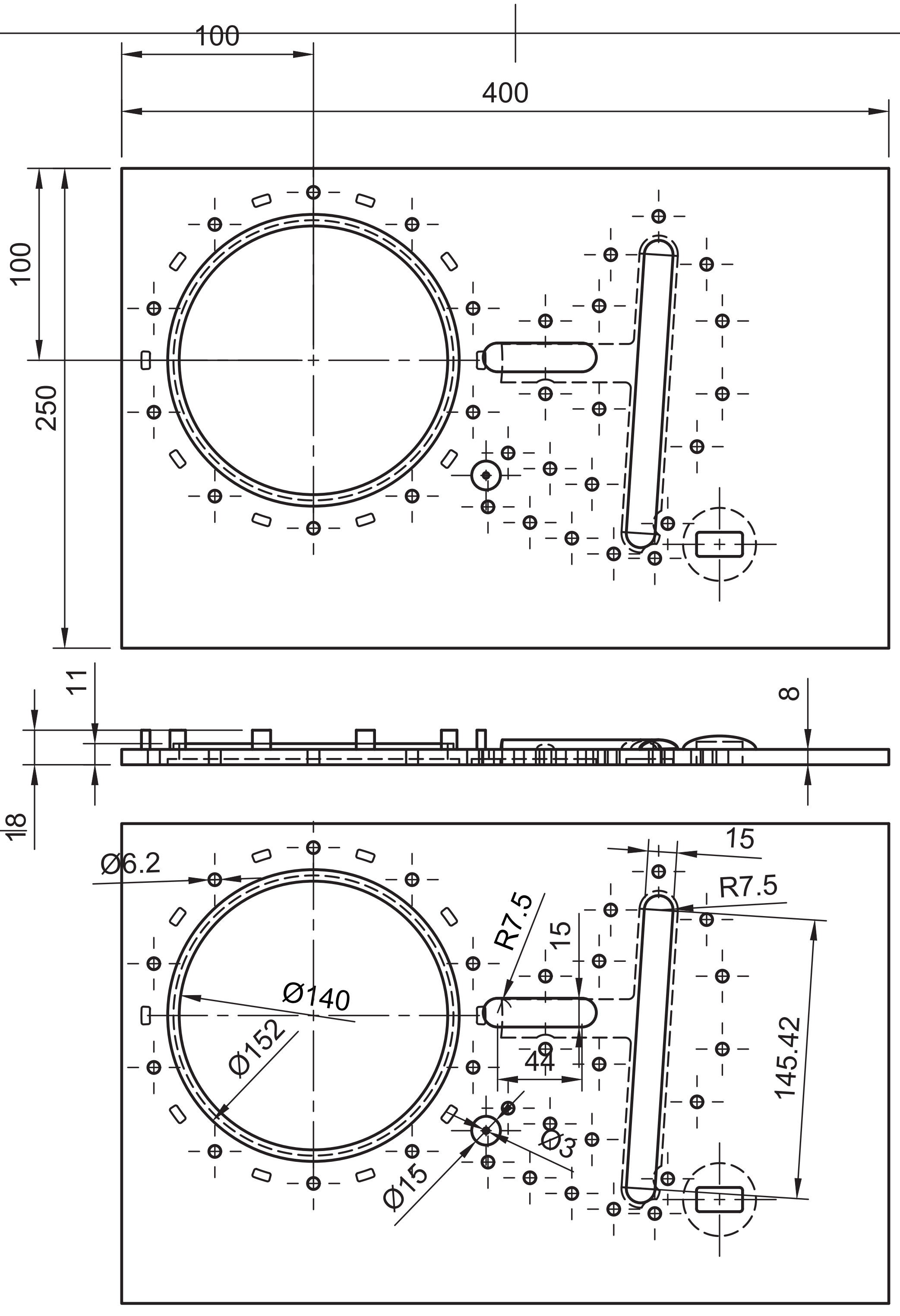

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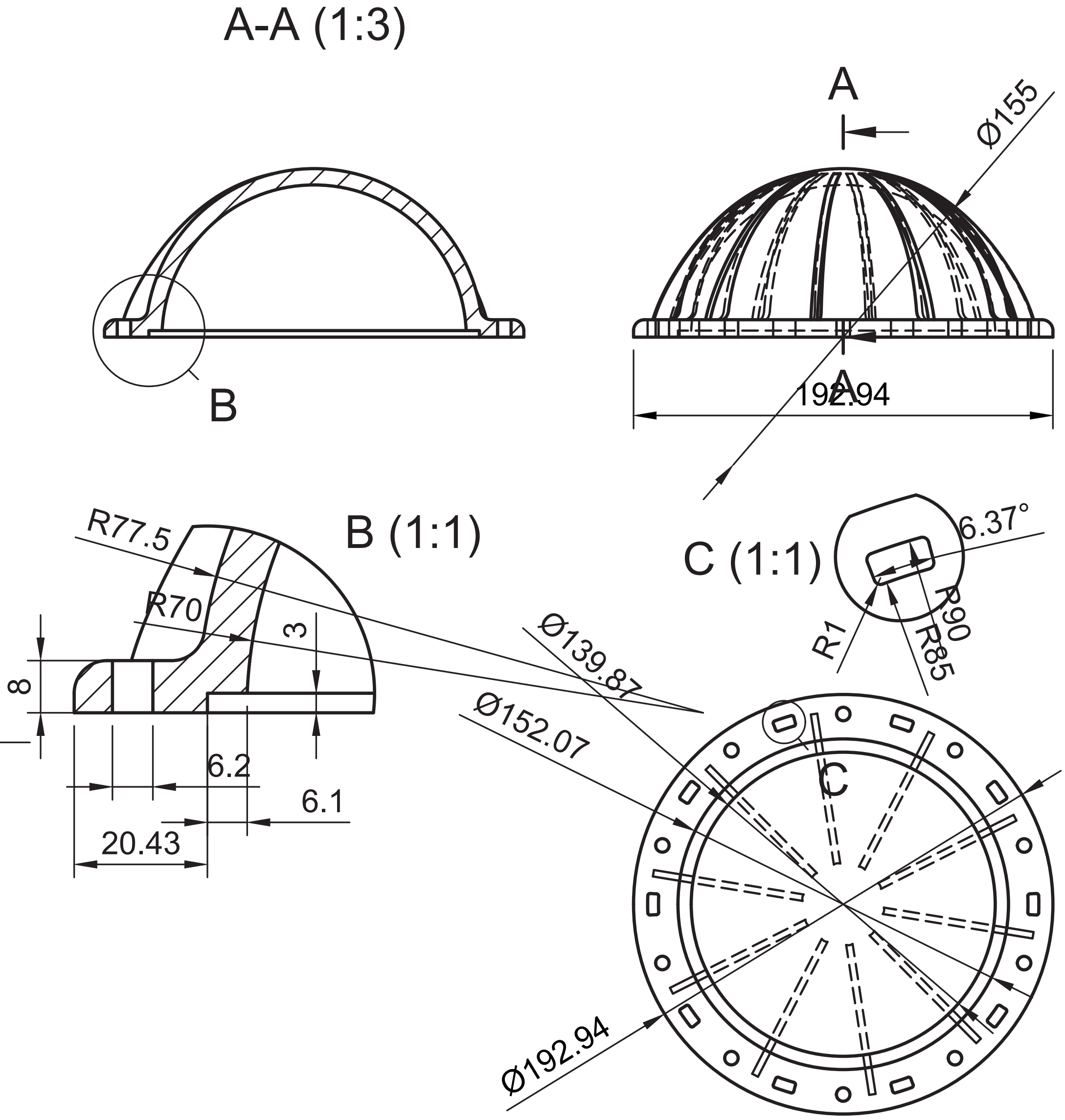

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Z E F

Appendix Q - Seal design

Introduction

Canals, valves and other components require integration in the three plated backbone sample. Therefore, sealing is required to prevent leaking the cavities within the backbone plate to one another and outwards. This implies circular and non-circular seals are necessary. Since pressures up to 50 bar are in involved in the system, literature on design for sealing applied on pressure vessels is consulted. Design for sealing is an expert area on its own. Only limited time is reserved to research, design, test and implement seals in the backbone sample. Hereunder an overview of the tests performed, along with the variables, findings and limitations of the design. The appendix is concluded with recommendations regarding seal design.

Equipment

The equipment used to perform the tests is listed below. The test-set up required a connector from the water pump towards a seal holder. Sven Buysse, intern of ZEF 2, helped with the manufacturing of these pieces. He also assisted at carrying out the seal tests. Figure 19 and 20 , provide an overview of equipment used.

- 70bar hand powered Water pump
- 3D printer for manufacturing PLA molds
- Svenector
- Male and female POM seal holder
- Teflon tape
- Clamp
- Silicone shore 50 compound A and B.

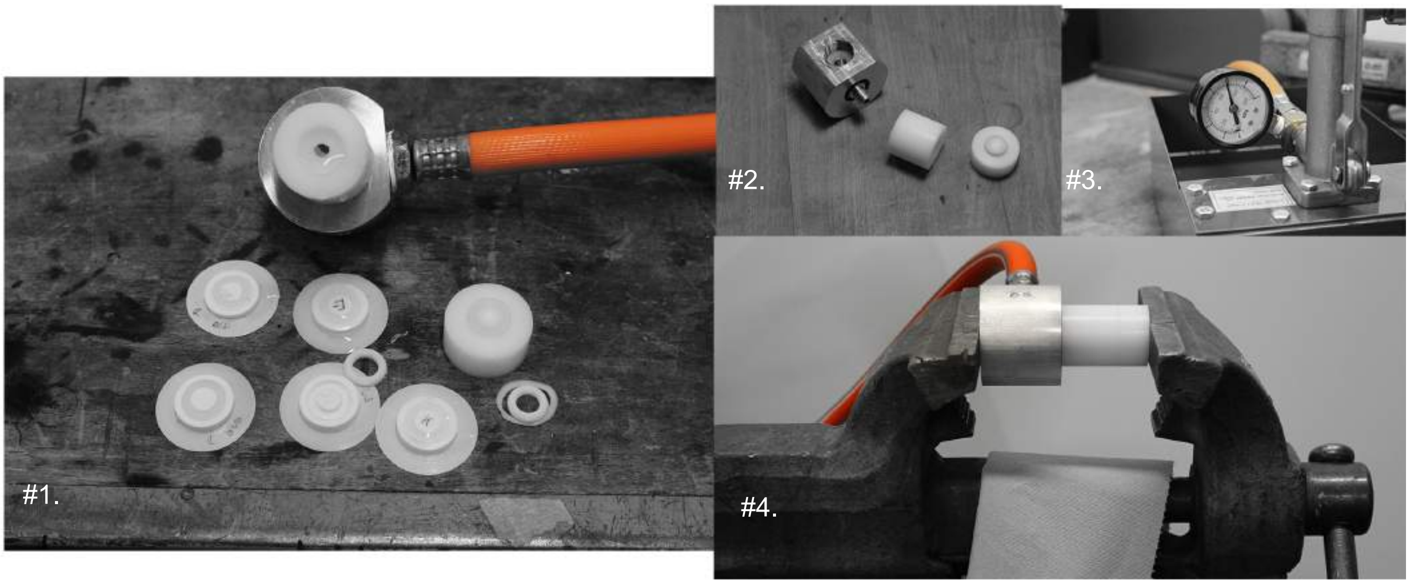


Figure 19.

1. Different radial seal design tested

#2. The “Svenector”, a connector made by Sven of Team ZEF 2, designed to mount the water inlet upon and a seal holder made out of POM.

#3. A waterpump to perform the testing with, here a pressure of 50bar is applied on a seal

#4. A seal ready to test, mounted in a clamp, a paper is lying beneath to quickly spot any leakages

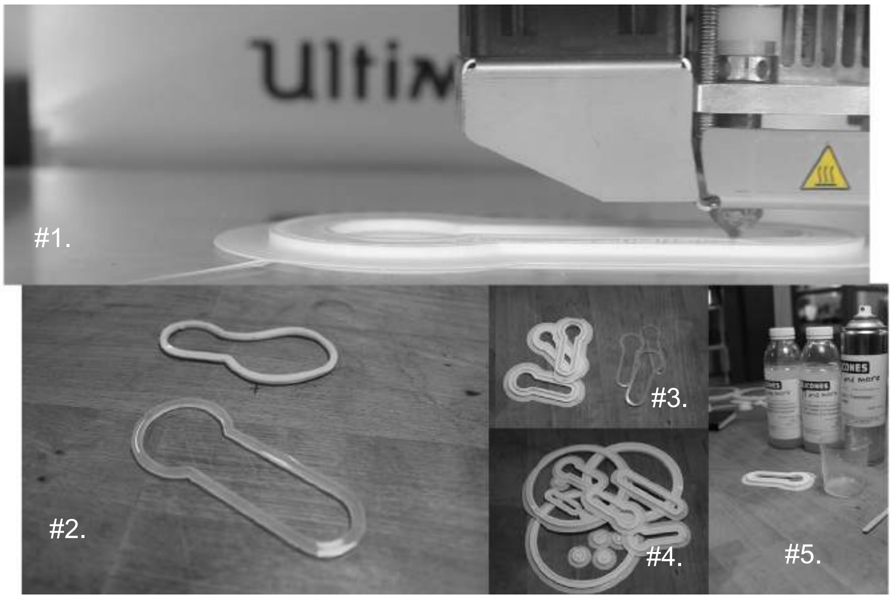


Figure 20. Overview equipement used part one

#1. 3D printer at work, the mold of a solenoid seal

#2. Several types of silicone tested for the seals, shore 50 is found to be the thoughest and best

#3. The different solenoid mold iterations, involves slight adaptions to cross-sections and contour-lines

#4. The backbone sample requires 7 different seals, here all molds printed assembled

#5. The tools required to cast the molds with shore 50 silicone, a hardening time of 3 hours is required

Variables

Design

The design of the seals has been driven by iterative design. Design, prototype, test, reflect, iterate, prototype,… the design of the seals involves two things. The design of the seal itself and the design of the mold. Since non-circular and thus custom seals are required it is decided to manufacture them by myself. Therefore the design of a seal is two-fold. The design of the seal itself and the design of the mold. Figure 21 communicates the design of seals in Fusion 360. Based upon literature a first design is made and iterated upon. The evolution of the design is found in figure 22.

Seal material

As the seals are to be made by myself, a material had to be determined. Silicone had been used by team ZEF 1 for sealing the DAC chambers. First tests with this type of silicone resulted in the search to a more rigid silicone. Soon Silicone shore 50 was found suitable to start testing with.

Testing

During testing other parameters than the actual design of the seal play a role. The variables listed below where researched and tested whether they had any influence on the seal design.

Positioning seal in cavity

The seal holder consists of a male and female holder. Since the casted seals are not round, it is tested whether any difference is obtained by changing the orientation of the seal within the seal-holder. Test showed no difference.

Clamping force

The “svenector” and female part of the seal holder are leak tight connected by a thread connection. In order to prevent the male part from moving, a clamp is used to keep the test set up in place. This way, the seal design is tested accurately. Water can only get out through the seal. If the seal holds the pressure, the design is considered valid for backbone implementation. However, during testing no torque wrench was available to apply the same amount of force on the clamp with every test. In theory, the seal holder could be sealed by applying a lot of force on the clamp. Hence, the axial seal properties of the material are tested. Testing proved this statement right. More about this topic in the findings.

Wet vs dry seal mount

Whenever the seal holder was not properly dried after testing and immediately used for another test, the test failed. It has been assumed that water gets trapped once pressurized, and is forced its way out due to a lack of volume in the seal cavity. Whenever the water gets out, the seal finds a way out as well and a leak happens to occur. This theory has not been validated with the working seal design.

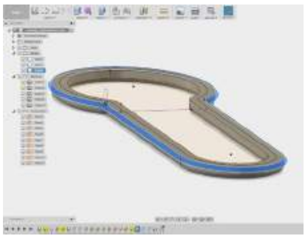


Figure 21. Overview equipment used part two

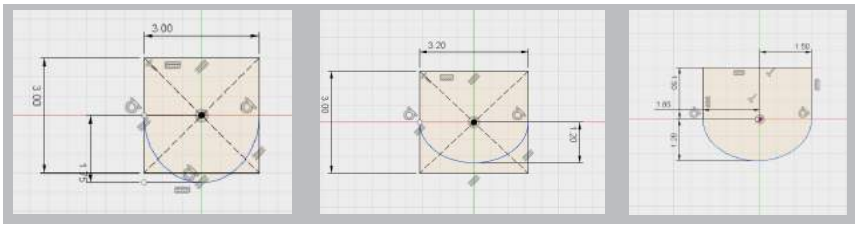


Figure 22. Design of seals in Fusion

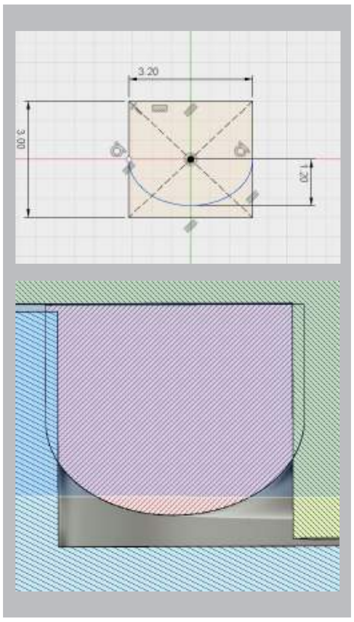


Figure 23. Evolution of seal design for a seal cavity of 3x3mm

Figure 24. Radial Seal design

Use of oil
Every design has been retested by applying some oil to the seal while mounting in the cavity. It has been assumed that oil stimulates the seal to deform in the intended way. This theory has not been validated with the working seal design

Findings

Achievement
The radial seal design found in figure 23 is capable of holding a pressure 50 bar over a period of 24hours. In order to be sure whether the seal holder has not been tightened too much by the clamp, the clamp has been released until a gap of 0.5 to 1mm between the male and female seal holder. This proves the radial seal to work.

Non-circular seal design
The seal design involves the compression by both the male and female part at the sides. Consequently, the seal cavity allows the seal to expand up and downwards. This design has been applied in the whole backbone sample. However, when mounting a non-circular seal with the same cross-section design, the seal tends not to work. No tight closure of seal and non-circular cavity is obtained. It got stretched over the widest points. (Figure 24)

Thus for the non-circular cavities within the backbone sample the design of the seal is adapted to a coincident connection with the cavity border and only a compression at the other side of the seal. Figure 25 provides more clarity.
Requirements for the backbone sample: male/female design.
Tests indicate that a male and female part are required in the backbone design to house a radial seal. The volume of the cavity created should always be bigger than the cross-section of the mounted seal. With regard to the design of these male and female borders, sharp and sudden transitions are to be avoided. Seals could get damaged whilst mounting.

Limitations

A first limitation with regard to the pressure tests performed is about the fact that only radial seals of a circular type have been tested. Meaning that the non-circular radial seal design has only been theoretically validated. It has not been tested prior to computer numerical controlled (CNC)-milling the backbone sample. Other limitations involve slight differences in quality among seals due to bubbles caused by casting and a slight difference in mixing the silicone compounds for pouring and casting the molds.

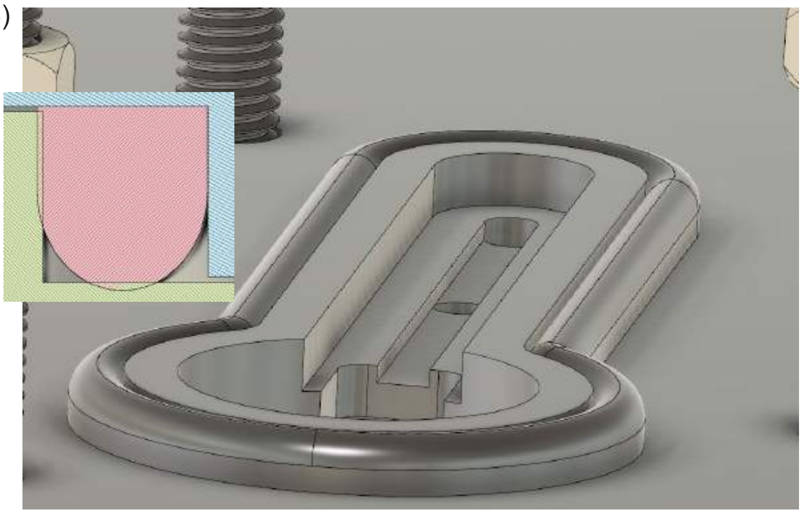


Figure 25. problems non-circular radial seal design

Recommendations

The pressure test is performed with only a small cavity to seal at high pressure. Whenever this cavity increases in volume, the forces on the seal are increased as well. Most ideally, radial seal design is to be tested for larger cavities as well. Another possible parameter to take in account with regard to testing for larger cavities is the change in seal cross-sectional area. It would be interesting to research whether for larger cavities a larger seal cavity is required, and how this relation behaves for increasing to be sealed cavity volumes. Finally, seals are only a contemporary solution. In the final design these are to be avoided as much as possible. Too much risk is bound to their functioning and behavior. Whenever seals are required at a later point in time in the final design of the backbone or microplant, standard seals are recommended or 2K-injection molding. The latter reduces the amount of parts. Hence, whenever a leak happens to occur the complete part requires replacement.

Appendix R - Subsystem Integration

Introduction

This Appendix is about a preliminary search into detail design which can be used for the integration of sub-systems. As mentioned in Chapter 3, this thesis focusses on the design of the backbone which only goes from a canal towards a component to integrate to another canal. The connection between subsystem to backbone has not been designed since these are still in full development. Only at a later stage these will be looked into. Undoubtedly, findings from the integration of components regarding sealing and mount can be used as an inspiration for the integration of subsystems. Within this line of thought some more options popped to my mind and have further been explored via sketching. (Figure 26)

Results

An important consideration prior to the connection to establish is whether the connection must be permanent. Within this ideation, the emphasis is laid upon design for disassembly and replaceability. This research is based upon the thought of why not just screw in PET pre-molds as a subsystem or buffer? These are perfectly capable of maintaining the pressure, are cheap, a lot of knowledge with regard to injection molding is researched and they can easily be replaced. One of the findings, based upon pressure vessel design is the usage of thread. Thread is relatively easy to injection mold and is one of the better methods to hold higher pressures. Fact is, the longer the thread the more secure the connection, but the more deeper the backbone must be. A trade-off is to be made to keep the material amount as low as possible and design a safe and reliable connection. This can be verified by FEM and Topology optimization.
Another method than tread involves the use of radial sealing, which is dealt with in Appendix Q. An interesting idea is the combination of a snap finger, thread and seal. Via the thread, the snap finger is tightened into place and hereby sealing the design. Disadvantage is the use of a compression seal. The principle is similar to the closing principle of a Gardena hose. In addition to the mount of the subsystem to the backbone, one should always be aware that a canal, a whole in the backbone) is to be connected to the subsystem.

Discussion

The ideas presented are rather straightforward and require further research whether they are useful or are patented. However, an opportunity in line with the thread, snap finger and seal concept, is to think of the usage of radial seals within the concept rather than compression seals. Furthermore, the PET-preform is an interesting idea in terms of a buffer. However, this most straight forward application requires no replaceability and is easily to be injection molded in one piece with the backbone. Nevertheless an interesting thought.

Conclusion

The PET-preform mount is to be added to the backbone opportunities board. Furthermore, the ideas pitched have some potential to look further into or to serve as a start whenever the integration of a subsystem on the backbone is needed. Thread alone, or in combination with radial seal design and snap fingers are promising for the reason they have applications in high pressure designs.

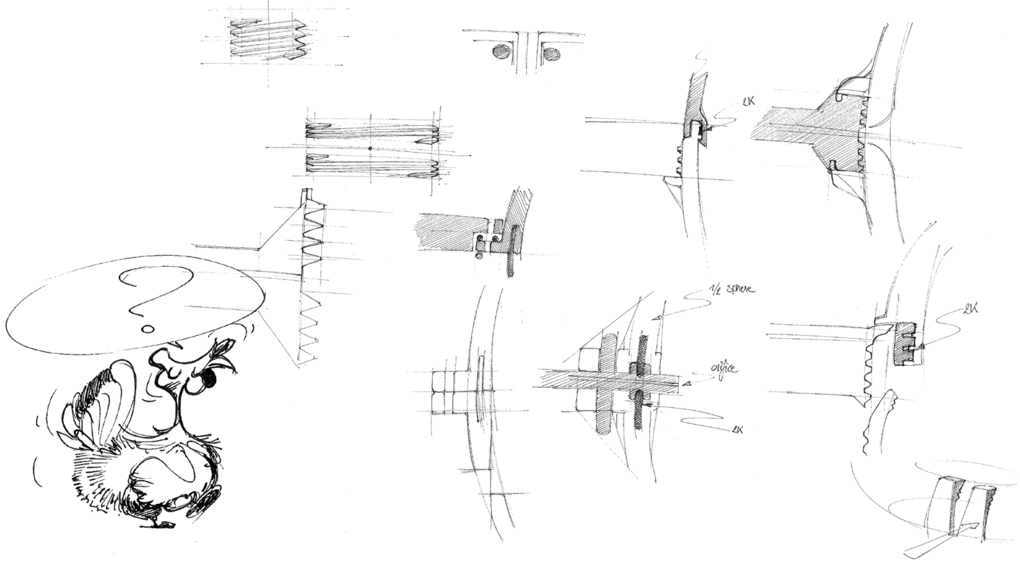


Figure 26. Ideation detail design for subsystem-backbone integrationOverview of the calculations made. Green are parameters bound to the design (retreived from the cost analysis) Blue are non fixed parameters.

Appendix S - Parameters Time to Market

This Appendix zooms in at the parameters used for the time to market calculation. Hereunder an overview of the parameters and values used. The calculation is based upon the assumption 1 injection mold machine per mold necessary is used. The calculation is about how long it takes to produce a production volume. Figure 27 provides an overview of the parameters involved, as well as the parameters to play with.

Working days per year	260	days
Amount of hours per day	8	hours
Machine set up time(preparation machine, material, tooling, testing and calibration)	16	hours
Injection time	1	sec
Cooling time	53	sec
Total cycle time(cooling time, injection time, safety factor of 2)	107	sec
Machine uptime per day	0.6	%
Success rate	**0.99**	%
Required production volume	**40000**	#
Production per day	159.88	# of Backbones/day
Days to produce required production volume	250.18	days

Figure 27. Example of a shear joint. Retrieved from DuPont Engineering Polymers, General Design Prinicples for Assembly Techniques - wleding, Adhesive bonding.(2000) p.25

Appendix T - Joining Techniques PET45% GF

Joining techniques for PET 45% GF can be found in literature. This appendix provides a brief overview of the possibilities regarding joint design for DuPont Engineering Polymers. (PET 45% GF is a DuPont Engineering Polymer) An important remark is that not all connections require permanent joints. Some parts bound to the backbone require replacement every 5 years, or should at least allow for replacement. Hereunder an overview of the techniques found apart from mechanical fasteners, press fits, snap fits and adhesion bonding.

The following design guides have been consulted regarding the overview:

- General Design Principles for DuPont Engineering Polymers
- General Design Principles for Assembly Techniques for DuPont Engineering Polymers

Spin Welding

“Spin welding produces welds that are strong, permanent and stress free. In spin welding, the part surfaces to be welded are pressed together as they are rotated relative to each other at high speed. Frictional heat is generated at the joint between the surfaces. After a film of melted thermoplastic has been formed, rotation is stopped and the weld is allowed to seal under pressure.” (DuPont Engineering Polymers, 2000)

Ultrasonic Welding

“Similar plastic parts can be fused together through the generation of frictional heat in ultrasonic welding. This rapid sealing technique, usually less than two seconds, can be fully automated for high speed and high production. Close attention to details such as part and joint design, welding variables, fixturing and moisture content is required.” (DuPont Engineering Polymers, 2000)

Vibration Welding

“Vibration welding is based on the principle of friction welding. In vibration welding, the heat necessary to melt the plastic is generated by pressing one part against the other and vibrating it through a small relative displacement at the joint. Heat generated by the friction melts the plastic at the interface. Vibration is stopped and the part is automatically aligned; pressure is maintained until the plastic solidifies to bond the parts together. The bond obtained approaches the strength of the parent material.” (DuPont Engineering Polymers, 2000)

Cold or Hot Heading

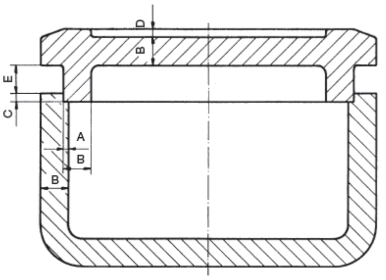
“This useful, low-cost assembly technique forms strong, permanent mechanical joints. Heading is accomplished by compression loading the end of a rivet while holding and containing the body.” (DuPont Engineering Polymers, 2000)

Discussion

Rubber parts may cause problems with regard to for instance Ultrasonic welding. They adsorb vibrations and often cause a weld to fail even at places far from the joint. Hence, all welding techniques require careful testing in advance. Also, each welding method requires design considerations. Which means different kind of joints come into play. Based upon the application a type of joint can be selected. In general the strength of the joint is linear with the depth of contact surface. The more surface in common the stringer the weld. Thus depth and strength are directly proportional. According to DuPont Engineering Polymers, the shear joint is the best joint for strong hermetic seals. (Figure 28)

Conclusion

Rubber parts in the backbone (seals) might cause welding techniques not to work due to adsorption of vibrations necessary to weld. For all welding techniques, the depth and strength of the seal directly proportional. The shear joint is found to be the best joint for strong hermetic seals. Furthermore, welding is only to be considered when no alternative for a one-piece backbone is found.



Dimension A	0,2 to 0,4 mm. External dimensions.
Dimension B	This is the general wall thickness.
Dimension C	0,5 to 0,8 mm. This recess is to ensure precise location of the lid.
Dimension D	This recess is optional and is generally recommended for ensuring good contact with the welding horn.
Dimension E	Depth of weld = 1,25 to 1,5 B for maximum joint strength.