ÉCOLE POLYTECHNIQUE DE LOUVAIN

UCLouvain

# LMAPR2020: Project 2
# Material Selection of a fire hose

Presented by Group L:

Gad Omar

Vansnick François

# *Introduction*

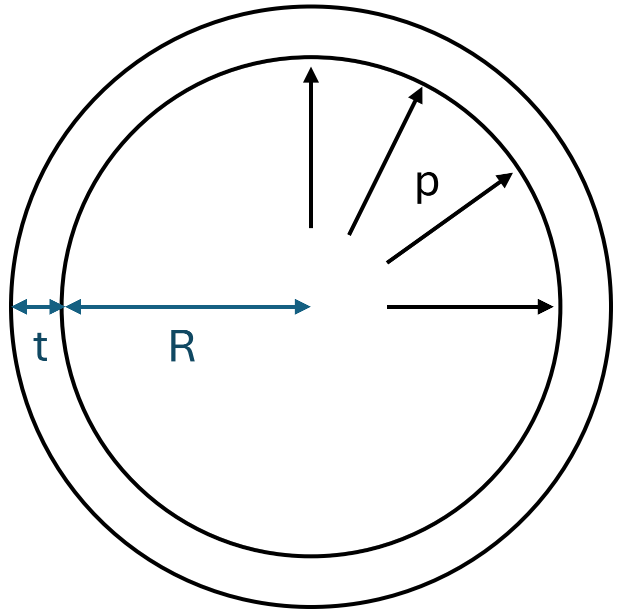
- Essential safety equipment for firefighting
- Use in crisis and in hostile environments
- Must be reliable and durable and easy to deploy under stress situation
- Focus on Type 3 fire hose (the most advanced, design for outdoor operations)


# Specifications

- Function: Carry water or fire retardant under high pressure to extinguish a fire
- Objective:
  - Minimize the mass to make it easily handled and transported by firefighters
  - Maximize the flexibility for easy storage and deployment
- Constraints:
  - Must withstand a continuous operating pressure of 15 bars without leakage or deformation
  - The hose must withstand a pressure of 45 bars without rupture
  - Working temperature range of -30°C to +80°C
  - Resistant to abrasion, chemicals and UV rays
  - Standardized internal diameter (45mm or 70mm) for compatibility with intervention equipment
- Free variables:
  - Material selection
  - Thickness

# *Material Index*

- <u>Pressure constraint :</u>
  - $dF = p \times (R\ L\ d\theta)$
  - $dF_x = dF\cos(\theta) = p\ R\ L\cos(\theta)\ d\theta$
  - $F_x = \int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} p\ R\ L\cos(\theta)\ d\theta = p\ R\ L \int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} \cos(\theta)\ d\theta = p\ R\ L\ 2$
  - $\sigma = \frac{F}{A} = \frac{F_x}{2t\ L} = \frac{2\ p\ R\ L}{2t\ L} = \frac{p\ R}{t}$



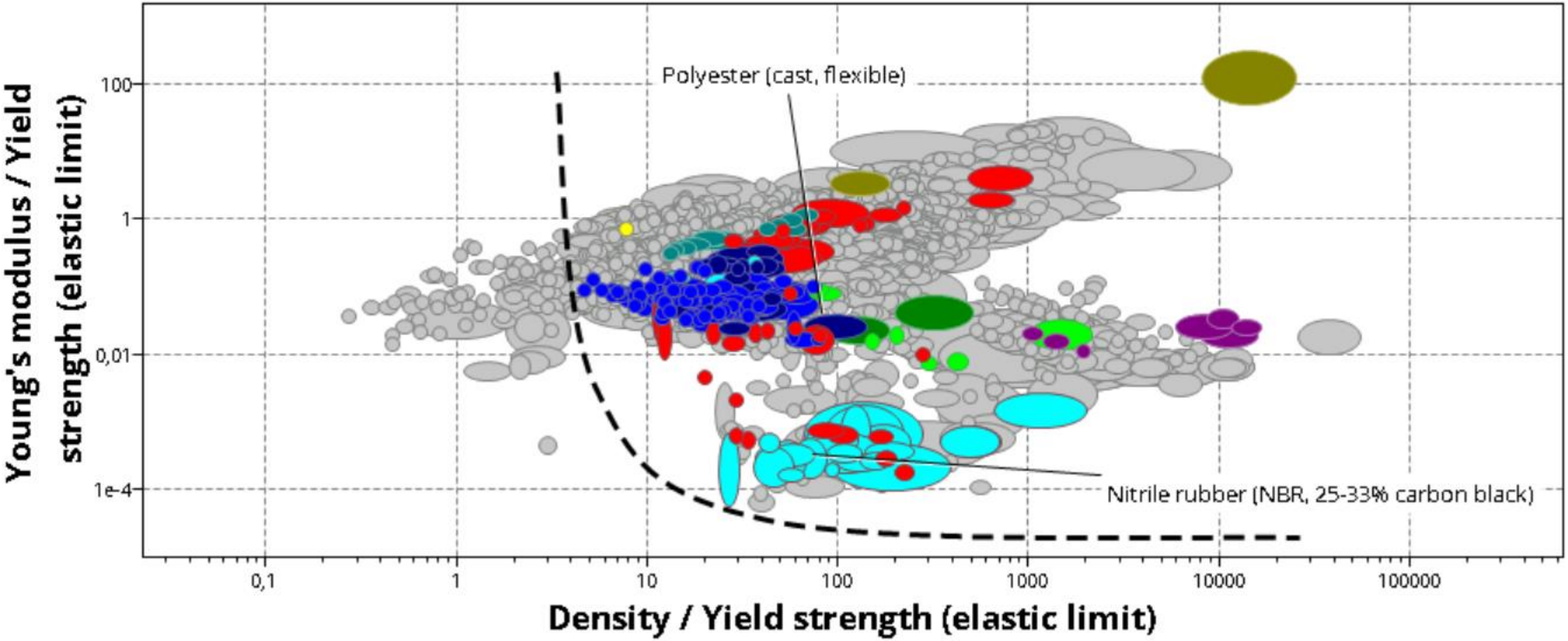

$$\boxed{\sigma = \frac{p\ R}{t}}$$

# Material Index

- Objectives :
  - $m = \rho \, V = \rho \, \pi \, L \, [\, (R + t)^2 \; - R^2] \approx \rho \, 2\pi \, L \, R \, t$
  - $S = \frac{1}{EI} = \frac{1}{E\pi R^3 t} \qquad (I \approx \pi \, R^3 \, t \; ; \; if \; t \ll R)$
  - Reminders : t (thickness) is a free variable
  - $t = \frac{pR}{\sigma_y}$
  - $m_1 = \frac{\rho 2 \, \pi L \, R^2 p}{\sigma_y} \;\Rightarrow\; M1 = \frac{\rho}{\sigma_y}$
  - $S_1 = \frac{\sigma_y}{E\pi R^4 p} \;\Rightarrow\; M_2 = \frac{E}{\sigma_y}$

$$\left.\begin{array}{l} M1 = \frac{\rho}{\sigma_y} \\ M_2 = \frac{E}{\sigma_y} \end{array}\right\} \quad Z = \alpha_1 \left(\frac{\rho}{\sigma_y}\right) + \alpha_2 \left(\frac{E}{\sigma_y}\right)$$

# Material Selection



# *Effective Properties of current fire hose*

**Polyester :**

$$\rho = 1105 \left[\frac{kg}{m^3}\right]$$

$$E = 0{,}3005 \ [GPa]$$

$$\sigma_y = 12{,}2 \ [MPa]$$

**Nitrile :**

$$\rho = 1115 \left[\frac{kg}{m^3}\right]$$

$$E = 0{,}00645 \ [GPa]$$

$$\sigma_y = 20 \ [MPa]$$

- We suppose f = 0.4

$$\rho = f \, . \rho_f + (1 - f)\rho_m = 0{,}4 \, . 1105 + 0{,}6 \, . 1115 = 1111 \left[\frac{kg}{m^3}\right]$$

$$E_V = f \, . E_f + (1 - f) \, E_m = 0{,}4 \, . 0.3005 + 0{,}6 \, . 0{,}00645 = 0{,}1241 \, [GPa]$$

$$\frac{1}{E_R} = \frac{f}{E_f} + \frac{(1 - f)}{E_m} = \frac{0{,}4}{0{,}3005} + \frac{0{,}6}{0{,}00645} = 94{,}354 \Rightarrow \ E_R = 0{,}0106 \, [GPa]$$

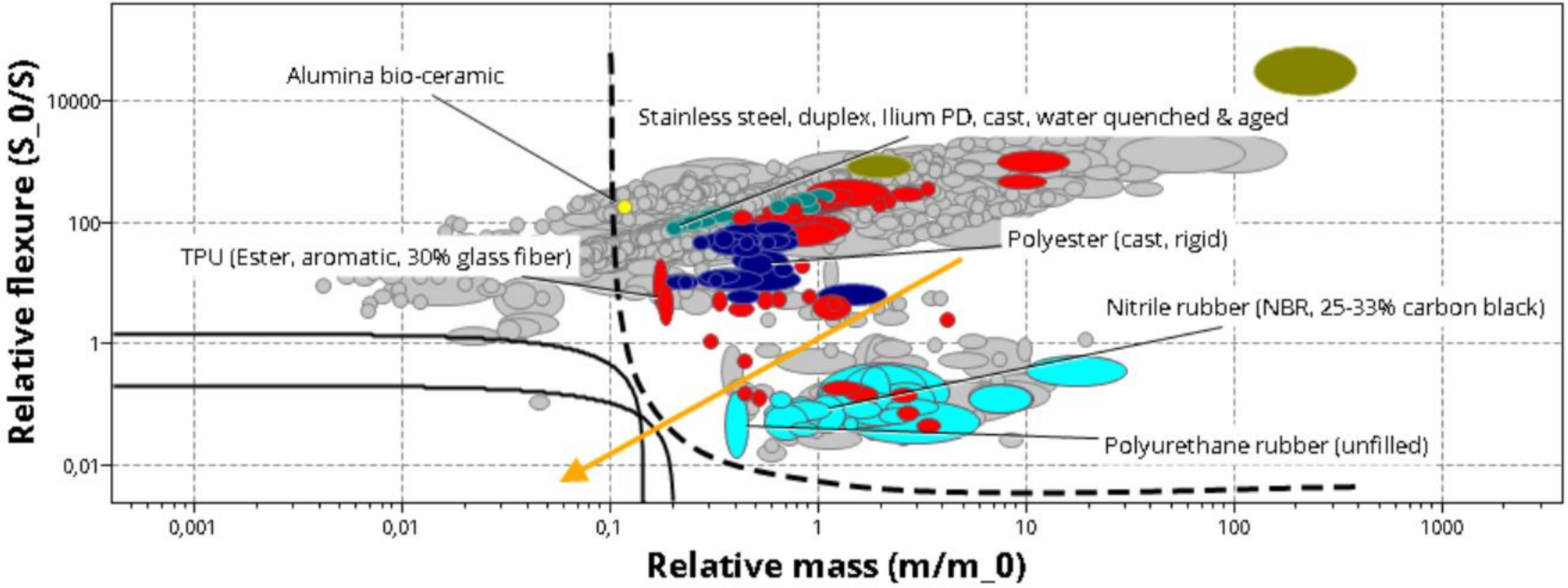
$$E_{average} = \frac{E_V + E_R}{2} = 0{,}0674 \, [GPa]$$

$$\sigma_y = f \, . \sigma_{y,f} + (1 - f) \, \sigma_{y,m} = 0{,}4 \, . 12{,}2 + 0{,}6 \, . 20 = 16{,}88 \, [MPa]$$

# *Comparison with current fire hose*

Relative penalty function comparison with current fire hose :

$$\frac{m}{m_0} = \left(\frac{\rho}{\sigma_y}\right) \cdot \left(\frac{\sigma_{y,0}}{\rho_0}\right) \quad \& \quad \frac{S_0}{S} = \left(\frac{E}{\sigma_y}\right) \cdot \left(\frac{\sigma_{y,0}}{E_0}\right) \qquad Z^* = \alpha_m^* \left(\frac{m}{m_0}\right) + \alpha_S^* \left(\frac{S_0}{S}\right)$$



# *Potential Material Candidates*

- Nitrile rubber:
  - Very high resistive pressure
  - Not very flexible
  - Very good abrasion and chemical resistance
  - **Good candidate for matrix material**
- VE (Vinyl Ester flexible):
  - Not very resistive
  - Not very flexible
  - Not resistive to acid
  - **Can't be use for our application**
- Polyester
  - High-pressure resistance
  - Not resistive to acid and UV
  - **Good candidate for fiber material**
- Polyurethane rubber (unfilled):
  - Bad resistance pressure
  - Very high flexibility
  - Bad UV resistance
  - **Good candidate for matrix material**
- Stainless Steel:
  - High pressure resistance
  - Very heavy
  - **Potentially use as fiber but is difficult to braid**
- Alumina (Ceramics) :
  - High pressure resistance
  - No flexibility
  - Brittle
  - **Can't be use for our application**
- TPU (30% Glass Fiber)
  - High pressure resistance
  - Not very flexible
  - **May be a good compromise**

- Thanks to this analysis we understand why current fire hoses are made of Nitrile and Polyester.
- However, we can try to use Polyurethane with Polyester.

# Effective properties of our new hybrid

**Polyester :**

$$\rho = 1105 \left[\frac{kg}{m^3}\right]$$

$$E = 0{,}3005\ [GPa]$$

$$\sigma_y = 12{,}2\ [MPa]$$

**Polyurethane rubber :**

$$\rho = 1200 \left[\frac{kg}{m^3}\right]$$

$$E = 0{,}00275\ [GPa]$$

$$\sigma_y = 45{,}5\ [MPa]$$

- We suppose f = 0.4

$$\rho = f\ .\rho_f + (1\ - f)\rho_m = 0{,}4\ .1105 + 0{,}6\ .1200 = 1162\ \left[\frac{kg}{m^3}\right]$$

$$E_V = f\ .E_f + (1 - f)\ E_m = 0{,}4\ .0.3005 + 0{,}6\ .0{,}00275 = 0{,}12185\ [GPa]$$

$$\frac{1}{E_R} = \frac{f}{E_f} + \frac{(1\ - f)}{E_m} = \frac{0{,}4}{0{,}3005} + \frac{0{,}6}{0{,}00275} = 219{,}51\ \Rightarrow\ E_R = 0{,}00455\ [GPa]$$

$$E_{average} = \frac{E_V + E_R}{2} = 0{,}0632\ [GPa]$$

$$\sigma_y = f\ .\sigma_{y,f} + (1 - f)\ \sigma_{y,m} = 0{,}4\ .12{,}2 + 0{,}6\ .45{,}5 = 32{,}18\ [MPa]$$

# *Comparison*

| Material | Density [kg/m^3] | Young’s Modulus [GPa] | Yield Strength [MPa] | Price [euros/kg] |
|---|---|---|---|---|
| Nitrile + Polyester | 1111 | 0,0674 | 16,88 | 2,585 |
| Polyurethane rubber + Polyester | 1162 | 0,0632 | 32,18 | 2,325 |

- Our new composite seems to be better : slightly heavier but more flexible with better yield's strength and cheaper
- So why is this composite not used now?
  - Nitrile is **more resistant** to oils, fuels and chemicals than Polyurethane rubber
  - Nitrile has also a **better UV and high temperature resistance** than Polyurethane
  - Nitrile **bonds better with polyester** during manufacturing and **easier to manufacture**

**Nitrile + Polyester are therefore the best choice for this type of application**

# *Eco Audit*

| Hose | Materials | Recycle content | Expected life cycle |
|---|---|---|---|
| Hose 1: | NBR<br><br>PET | Virgin<br><br>Virgin | 12 years |
| Hose 2: | TPU<br><br>PET | Virgin<br><br>Virgin | 10 years |
| Hose 3: | TPU & Fiber Glass 30% | Virgin | 10 years |

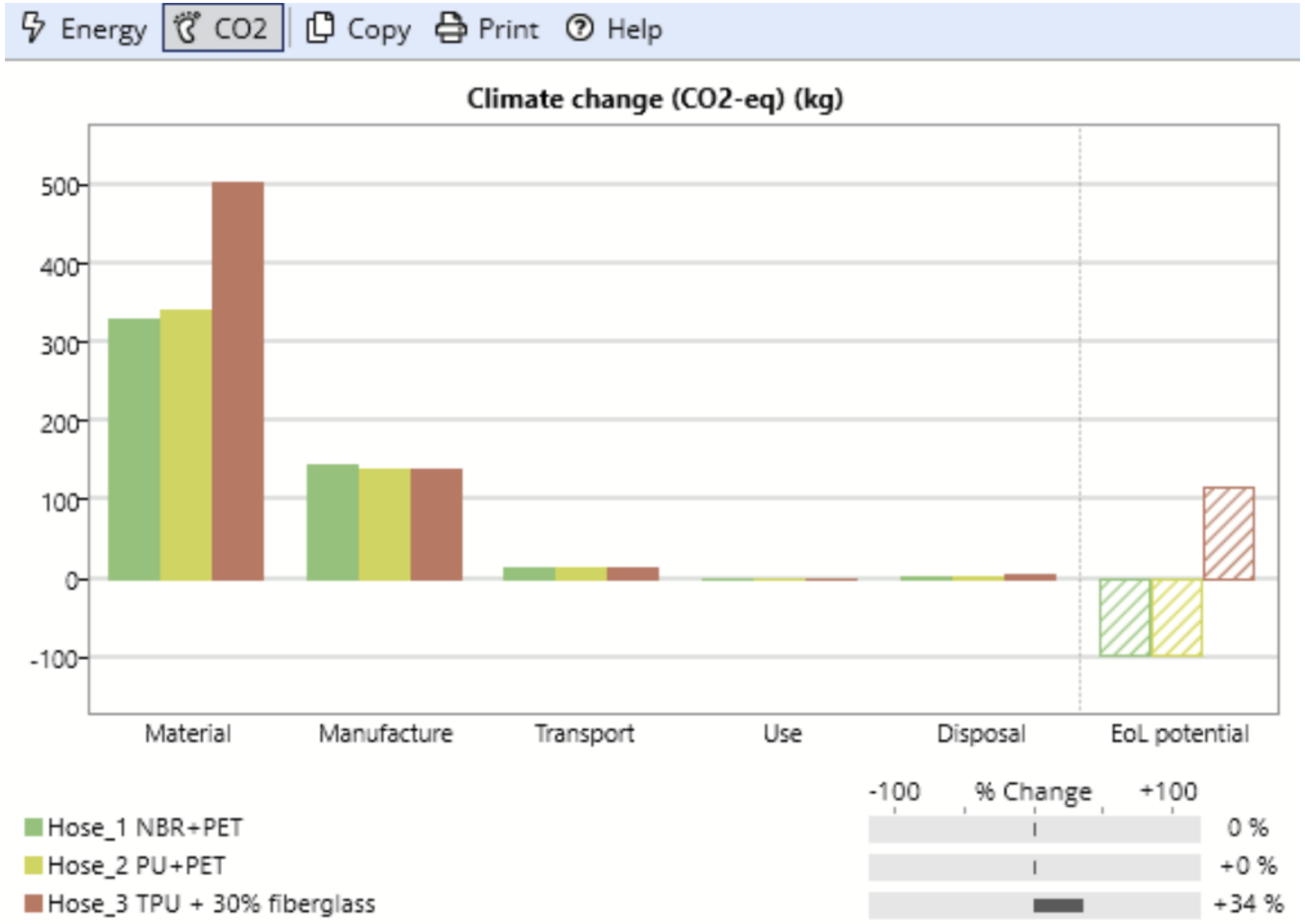
# End of life expectations

| Material | Recycling | Down-cycle | Combustion | Landfill |
|---|---|---|---|---|
| NBR | - | 100 % | - | - |
| PET | 100% | - | - | - |
| TPU | 95% | - | - | 5% |
| TPU + 30 % glass-fiber | - | - | 60 | 40 |

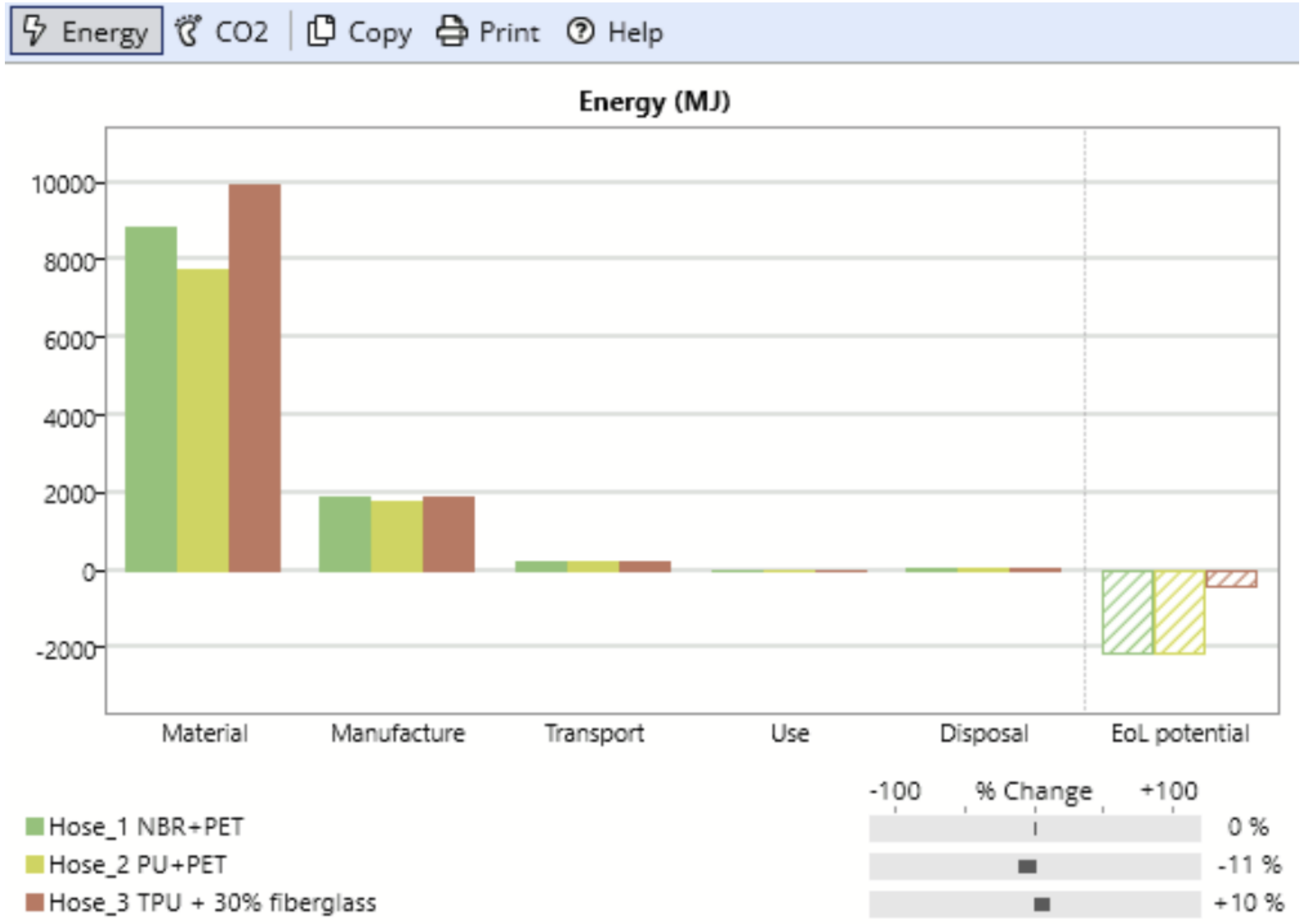
# *Transportation & suppliers*

| Material | Mean of trasportation | Distance | Supplier | Location |
|---|---|---|---|---|
| NBR<br><br>Acrylonitrile &Butadiene | Truck/pipeline | ≈250 km +<br><br>≈1000Km | LANXESS AG | Dormagen, Germany |
| PET<br><br>PTA & MEG | Truck/pipeline | ≈100 Km +<br><br>≈1000Km | Beaulieu Fibres International | Wielsbeke, Belgium |
| TPU<br><br>MDI & Polyether polyol | Truck/pipeline | ≈50 Km +<br><br>≈600Km | Nexeo Plastics | Antwerp, Belgium |

# Climate change



# Energy



Energy
CO2
Copy
Print
Help
Energy (MJ)
10000
8000
6000
4000
2000
0
-2000
Material
Manufacture
Transport
Use
Disposal
EoL potential
-100
% Change
+100
Hose_1 NBR+PET
0 %
Hose_2 PU+PET
-11 %
Hose_3 TPU + 30% fiberglass
+10 %

# New Selection

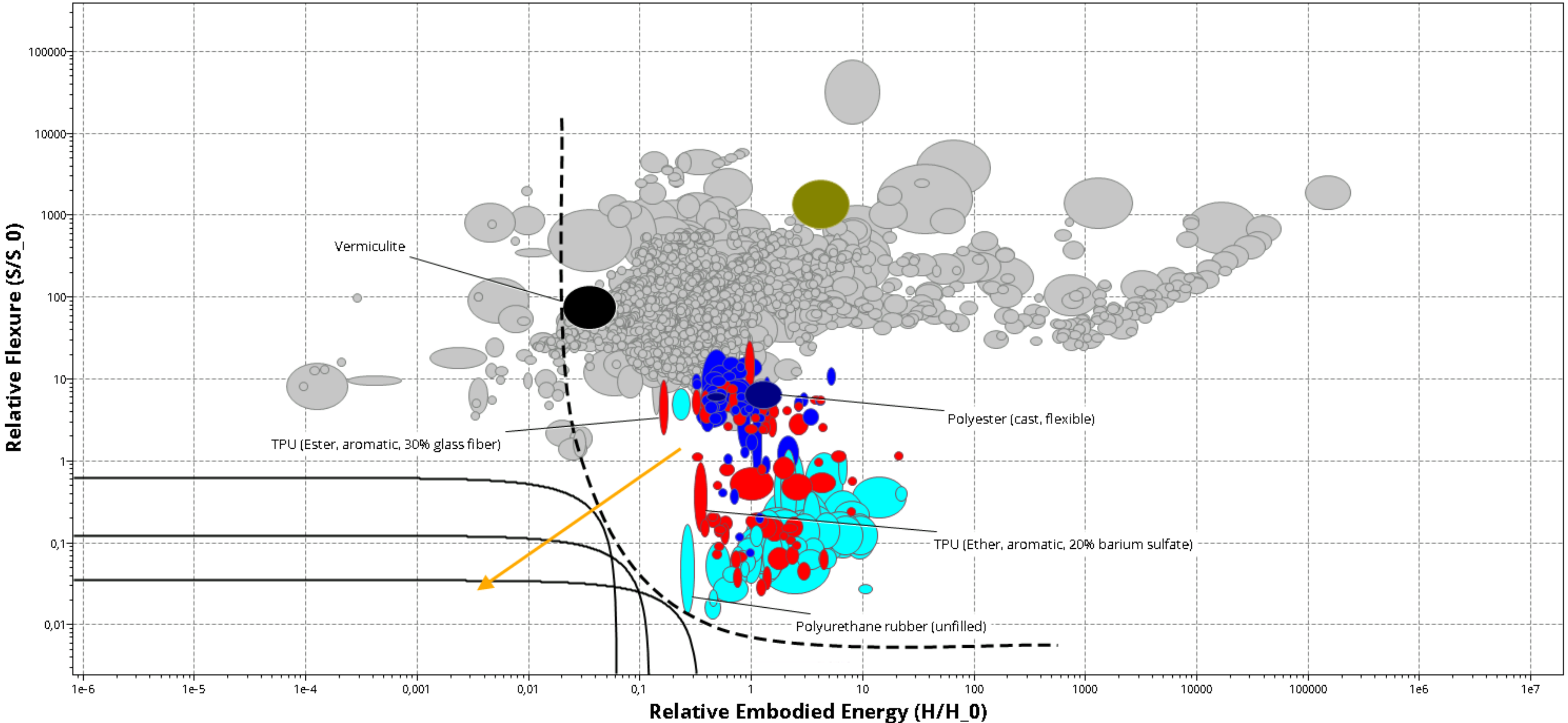
- Function: Carry water or fire retardant under high pressure to extinguish a fire
- Objective:
  - Minimize embodied energy (or $CO_2$ footprint)
  - Maximize the flexibility for easy storage and deployment
- Constraints:
  - Must withstand a continuous operating pressure of 15 bars without leakage or deformation
  - The hose must withstand a pressure of 45 bars without rupture
  - Working temperature range of -30°C to +80°C
  - Resistant to abrasion, chemicals and UV rays
  - Standardized internal diameter (45mm or 70mm) for compatibility with intervention equipment
- Free variables:
  - Material selection
  - Thickness

# New Selection

- Objectives :
  - $H_m\, m = H_m\, \rho\, V = H_m\, \rho\, \pi\, L\, [\,(R+t)^2\; - R^2] \approx H_m\, \rho\, 2\pi\, L\, R\, t$
  - $S = \frac{1}{EI} = \frac{1}{E\pi R^3 t} \quad (I \approx \pi\, R^3\, t\;\; ;\;\; if\; t \ll R)$
  - Reminders : t (thickness) is a free variable
  - $t = \frac{pR}{\sigma_y}$
  - $H = \frac{H_m\, \rho 2\, \pi L\, R^2 p}{\sigma_y} \;\Rightarrow\; M1 = \frac{H_m\, \rho}{\sigma_y} \quad (or \quad M1 = \frac{[CO_2]\, \rho}{\sigma_y})$ $\quad H_0 = \frac{H_m\, \rho 2\, \pi L\, R^2 p}{\sigma_y} = C\frac{H_{m_0}\, \rho_0}{\sigma_{y,0}} = \ldots$
  - $S = \frac{\sigma_y}{E\pi R^4 p} \;\Rightarrow\; M_2 = \frac{E}{\sigma_y}$

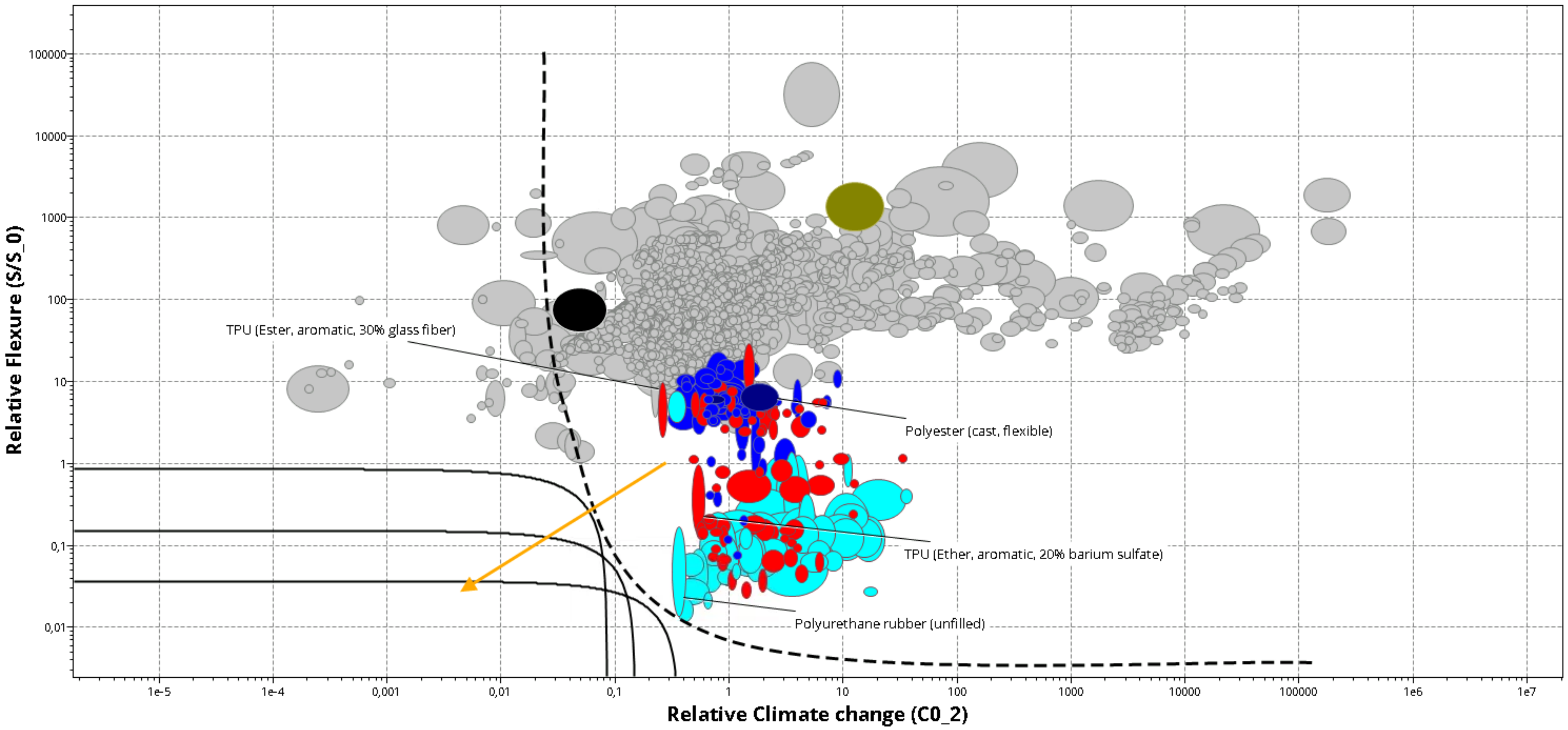
# New Selection

Relative penalty function comparison with current fire hose : $\frac{H}{H_0} = \left(\frac{H_m\,\rho}{\sigma_y}\right) . \left(\frac{\sigma_{y,0}}{H_{m_0}\rho_0}\right)$ & $\frac{S_0}{S} = \left(\frac{E}{\sigma_y}\right) . \left(\frac{\sigma_{y,0}}{E_0}\right)$



# *New Selection*

Relative penalty function comparison with current fire hose : $\frac{C}{C_0} = \left(\frac{CO_2\ \rho}{\sigma_y}\right) . \left(\frac{\sigma_{y,0}}{CO_{2_0}\rho_0}\right)$ & $\frac{S_0}{S} = \left(\frac{E}{\sigma_y}\right) . \left(\frac{\sigma_{y,0}}{E_0}\right)$



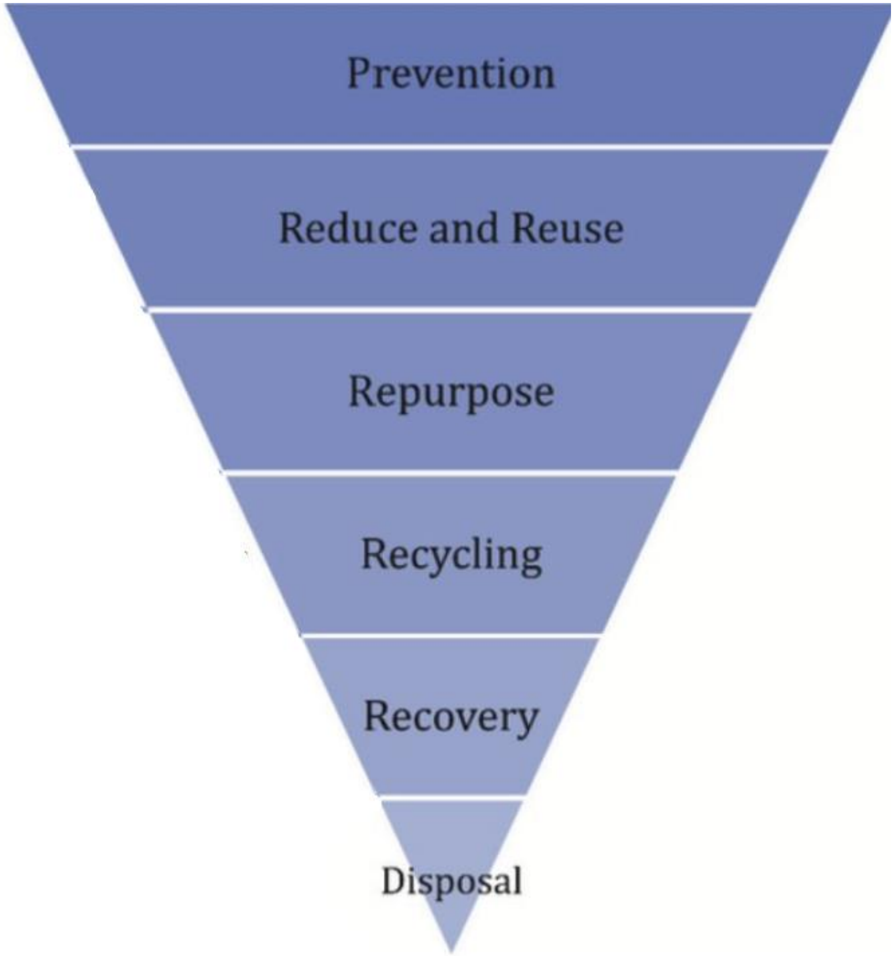

Polyurethane rubber + Polyester (cast, flexible)

# New Selection

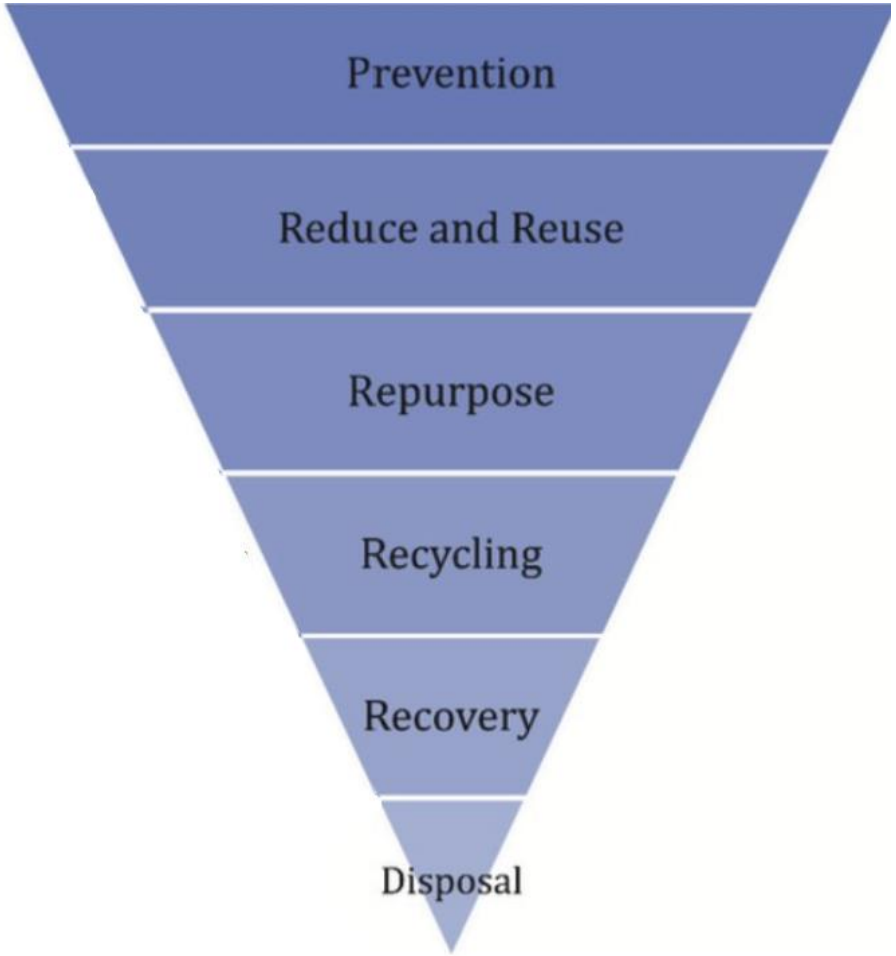
| Material | Density [kg/m^3] | Young's Modulus [GPa] | Yield Strength [MPa] | Price [euros/kg] | Embodied Energy [MJ/kg] | Climate change [kgC02/kg] |
|---|---|---|---|---|---|---|
| Nitrile + Polyester | 1111 | 0,0674 | 16,88 | 2,585 | 112,5 | 3,6 |
| Polyurethane rubber + Polyester | 1162 | 0,0632 | 32,18 | 2,325 | 83,58 | 3,74 |

- From an environmental point of view, Polyurethane matrix with polyester fibers is also the best compromise
- but as explained previously Nitrile and polyester is more widely used

# *Future recommendations*

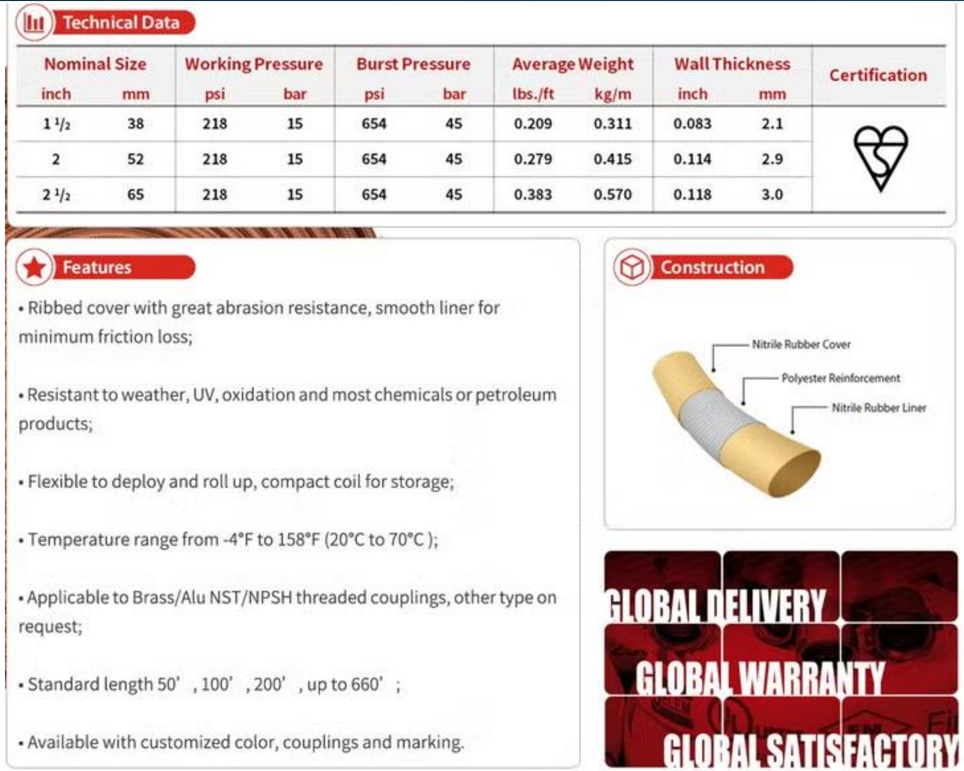


# *Future recommendations*



***Thank You***
***Any questions***

# References



Technical Data

| Nominal Size | | Working Pressure | | Burst Pressure | | Average Weight | | Wall Thickness | | Certification |
|---|---|---|---|---|---|---|---|---|---|---|
| inch | mm | psi | bar | psi | bar | lbs./ft | kg/m | inch | mm | |
| 1 1/2 | 38 | 218 | 15 | 654 | 45 | 0.209 | 0.311 | 0.083 | 2.1 | |
| 2 | 52 | 218 | 15 | 654 | 45 | 0.279 | 0.415 | 0.114 | 2.9 | |
| 2 1/2 | 65 | 218 | 15 | 654 | 45 | 0.383 | 0.570 | 0.118 | 3.0 | |

Features

- Ribbed cover with great abrasion resistance, smooth liner for minimum friction loss;
- Resistant to weather, UV, oxidation and most chemicals or petroleum products;
- Flexible to deploy and roll up, compact coil for storage;
- Temperature range from -4°F to 158°F (20°C to 70°C );
- Applicable to Brass/Alu NST/NPSH threaded couplings, other type on request;
- Standard length 50' , 100' , 200' , up to 660' ;
- Available with customized color, couplings and marking.

Construction





# References


- https://www.flowtech.co.uk/fire-hose-reel-guide/
- https://tpmcsteel.com/product/layflat-fire-hose-type-3/#:~:text=Layflat%20fire%20hose%20is%20typically,resistance%20to%20abrasion%20and%20heat.

# *Effective Properties*

**TPU :**

$$\rho = 1360 \left[\frac{kg}{m^3}\right]$$

$$E = 0{,}0354\ [GPa]$$

$$\sigma_y = 54{,}3\ [MPa]$$

**Polyamide fiber :**

$$\rho = 1140 \left[\frac{kg}{m^3}\right]$$

$$E = 4{,}5\ [GPa]$$

$$\sigma_y = 802.5\ [MPa]$$

- We suppose f = 0.4

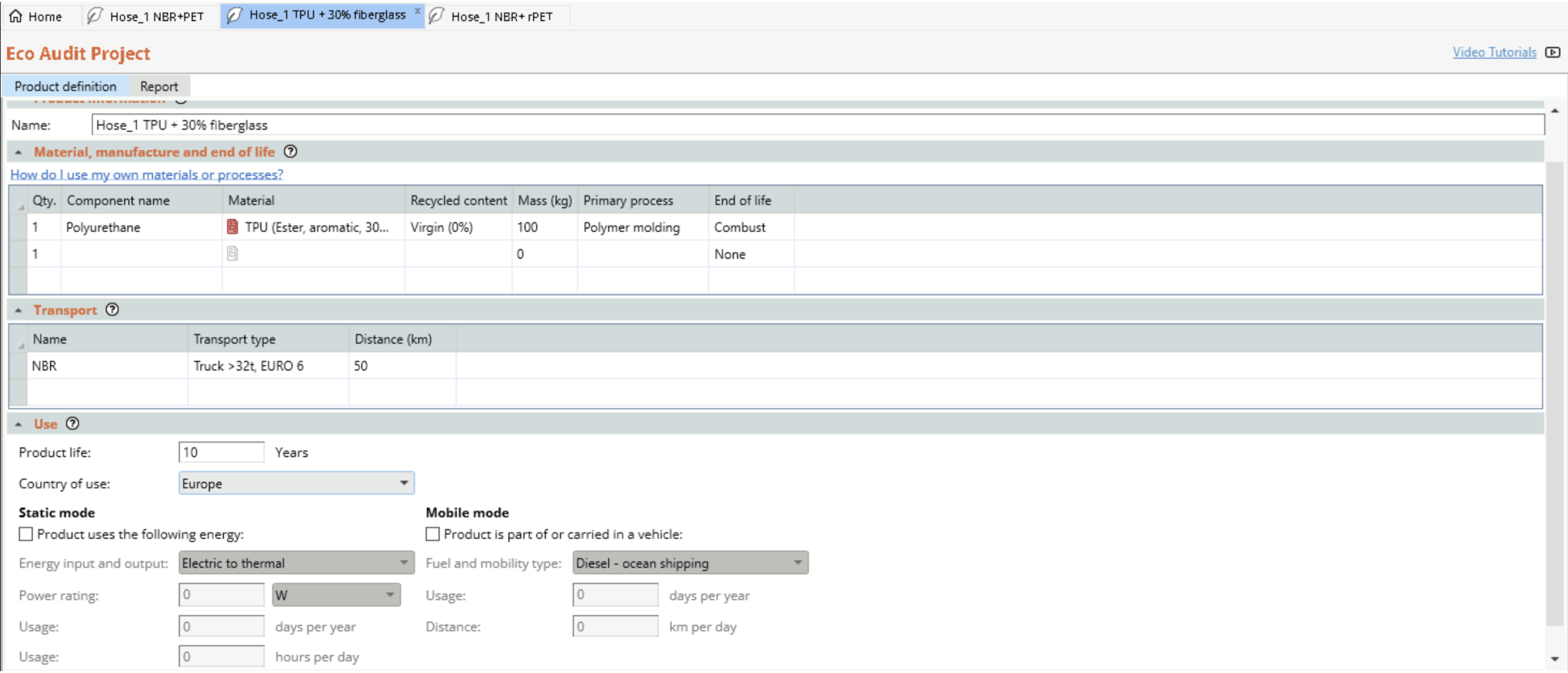
$$\rho = f\ .\rho_f + (1\ - f)\rho_m = 0{,}2\ .1140 + 0{,}8\ .\ 1360 = 1316 \left[\frac{kg}{m^3}\right]$$

$$E_V = f\ .E_f + (1 - f)\ E_m = 0{,}2\ .\ 4{,}5 + 0{,}8\ .\ 0{,}0354 = 1,1832[GPa]$$

$$\frac{1}{E_R} = \frac{f}{E_f} + \frac{(1\ - f)}{E_m} = \frac{0{,}2}{4{,}5} + \frac{0{,}8}{0{,}0354} = 22{,}64\ \Rightarrow\ E_R = 0{,}04416\ [GPa]$$

$$E_{average} = \frac{E_V + E_R}{2} = 0{,}6136\ [GPa]$$

$$\sigma_y = f\ .\sigma_{y,f} + (1 - f)\ \sigma_{y,m} = 0{,}2\ .\ 802{,}5 + 0{,}8\ .\ 20 = 203{,}94\ [MPa]$$


Home
Hose_1 NBR+PET
Hose_1 TPU + 30% fiberglass
Hose_1 NBR+ rPET
Eco Audit Project
Video Tutorials
Product definition
Report
Name:
Hose_1 TPU + 30% fiberglass
Material, manufacture and end of life
How do I use my own materials or processes?
Qty.
Component name
Material
Recycled content
Mass (kg)
Primary process
End of life
1
Polyurethane
TPU (Ester, aromatic, 30...
Virgin (0%)
100
Polymer molding
Combust
1
0
None
Transport
Name
Transport type
Distance (km)
NBR
Truck >32t, EURO 6
50
Use
Product life:
10
Years
Country of use:
Europe
Static mode
Product uses the following energy:
Energy input and output:
Electric to thermal
Power rating:
0
W
Usage:
0
days per year
Usage:
0
hours per day
Mobile mode
Product is part of or carried in a vehicle:
Fuel and mobility type:
Diesel - ocean shipping
Usage:
0
days per year
Distance:
0
km per day