Einstein Telescope Bake-out and Insulation Options

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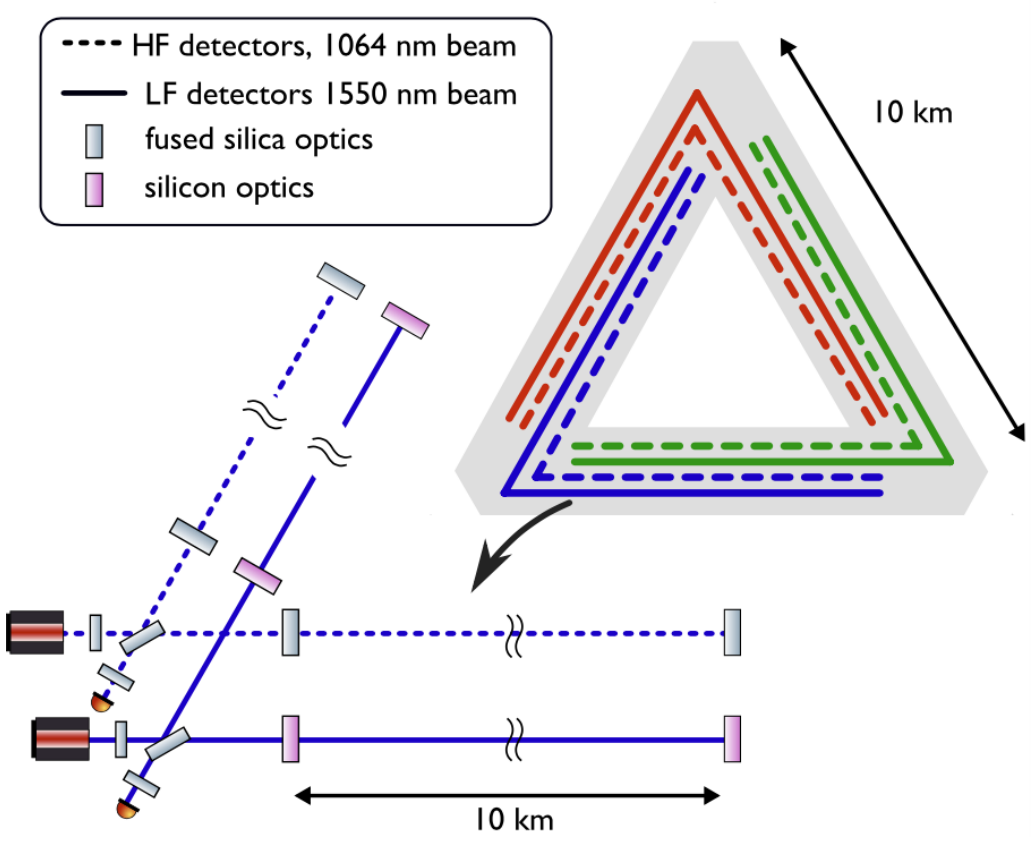
Contents

- Introduction to Einstein Telescope project.
- Einstein Telescope bake-out system.
- Thermal insulation
- Next steps and final considerations

Introduction to the Einstein Telescope Project

- New 3rd generation detector to build upon the success of the current generation detectors.
- Increased sensitivity of at least 10 times that of LIGO and VIRGO
- Consists of three 10km tunnels, 3 detectors and 6 interferometers (2 per detector)
- 1m beampipe diameter



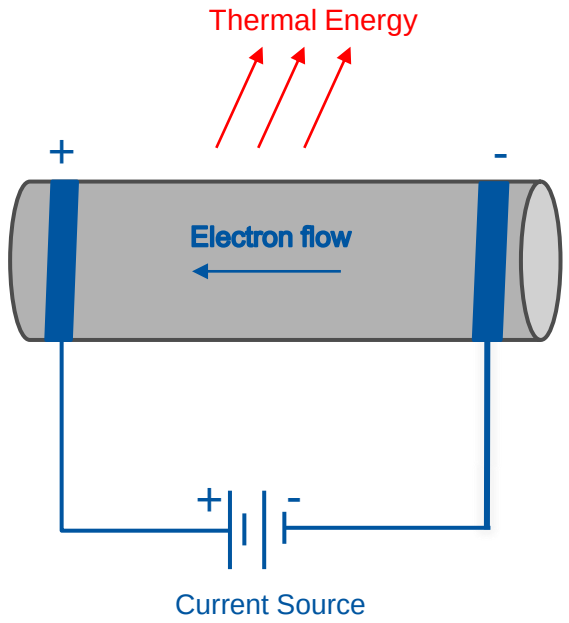
Einstein Telescope Bake-out

- Bake-out using Joule Effect (I^2R) heating of the vacuum chambers
- “Traditional” heating of the pumping modules using heating bands, jackets, etc.
- Low temperature, long duration bake-out cycle.
- Potentially one-time bake-out cycle

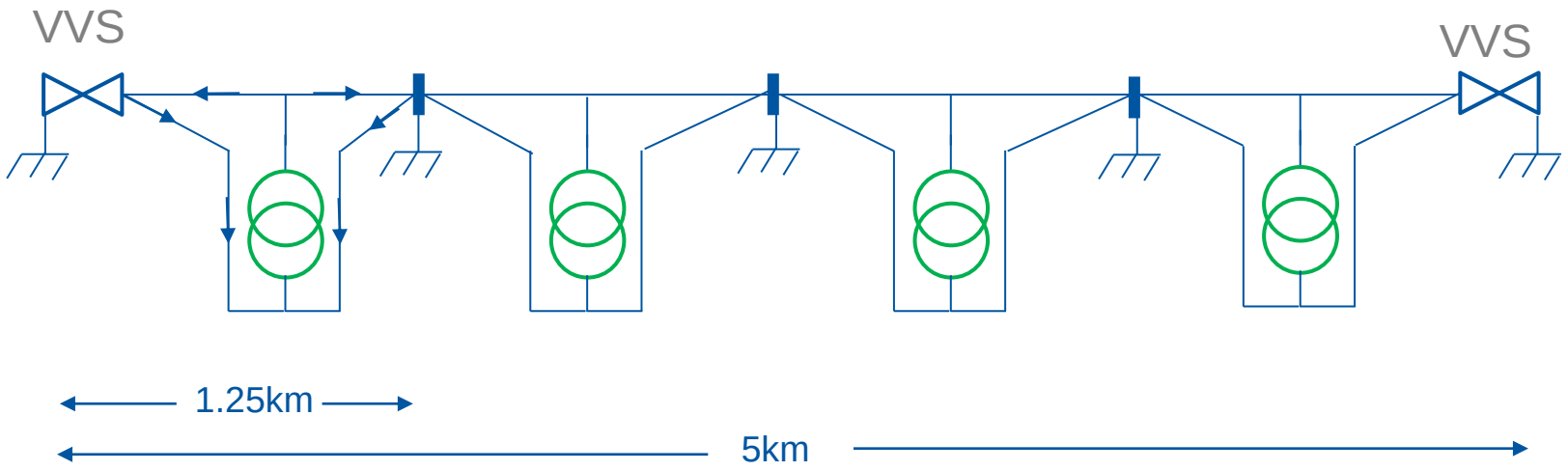
Principle of Joule Effect heating

- Passing of electrical current through a material to produce thermal energy.
- This thermal energy is a result of the opposition of the material to the electron flow within.
- Factors affecting the heating effect:
  - Resistance (R) of the conductor
  - Duration (t) for which current flows
  - Current (I) passing through

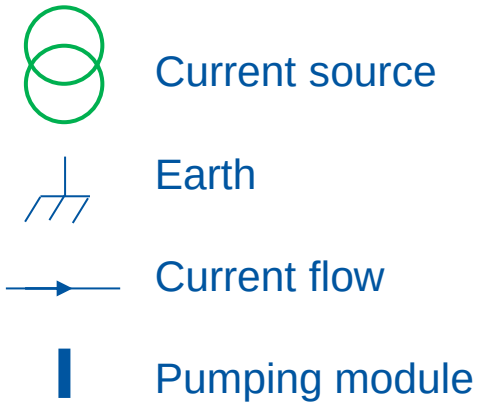
$$H = I^2Rt$$



Application of ET Bake-out System



	Corrugated Stainless Steel (1km, 1.3mm thick)	Mild Steel (1km, 3mm thick)
Resistance (mΩ/km)	250	34
Current (A)	540	1400
Voltage Drop (V/km)	135	50



Credit: G. Pigny

Insulation Budget

- If VIRGO insulation is scaled to the ET dimensions (120km – 379km^2):

Raw Material Costs: ~ €35M

- Additional 20-25M€ required for the pumping and sectorisation system.

*Reference: C. Scarcia, Beampipes for Gravitatonal Wave Telescopes (indico event: 1208957)

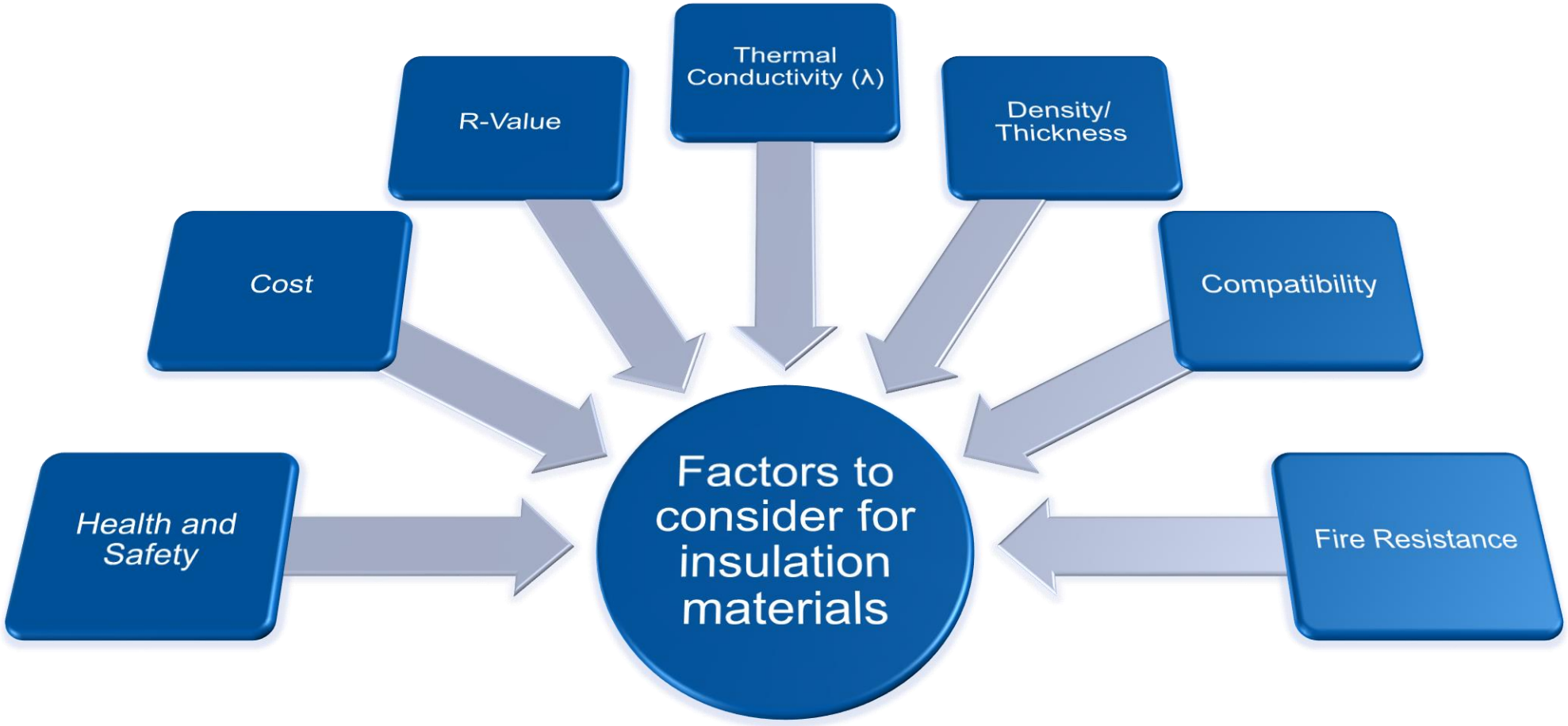
Why do we use thermal insulation during bake-out cycles?

Energy Conservation

Personnel Protection

Fire Protection

Factors to consider when choosing Insulation material?

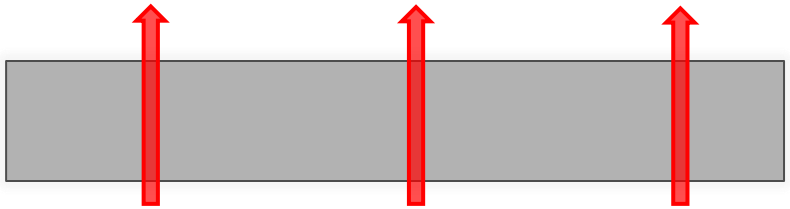


Thermal Conductivity Vs Thermal Resistance

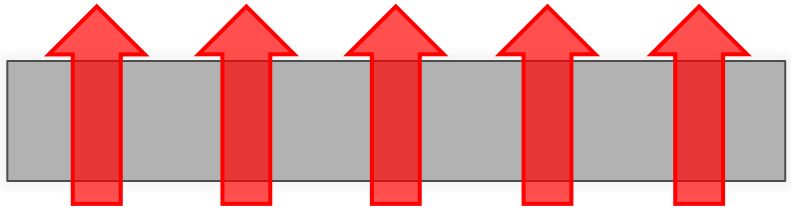
Thermal Conductivity (k/λ)
Measure of how easily heat flows through a material independent of thickness

Thermal Resistance (R-value)
Measure of the resistance of heat flow through a material for a given thickness.

Low λ/High R-value = Low Heat Loss



High λ/Low R-value = High Heat Loss

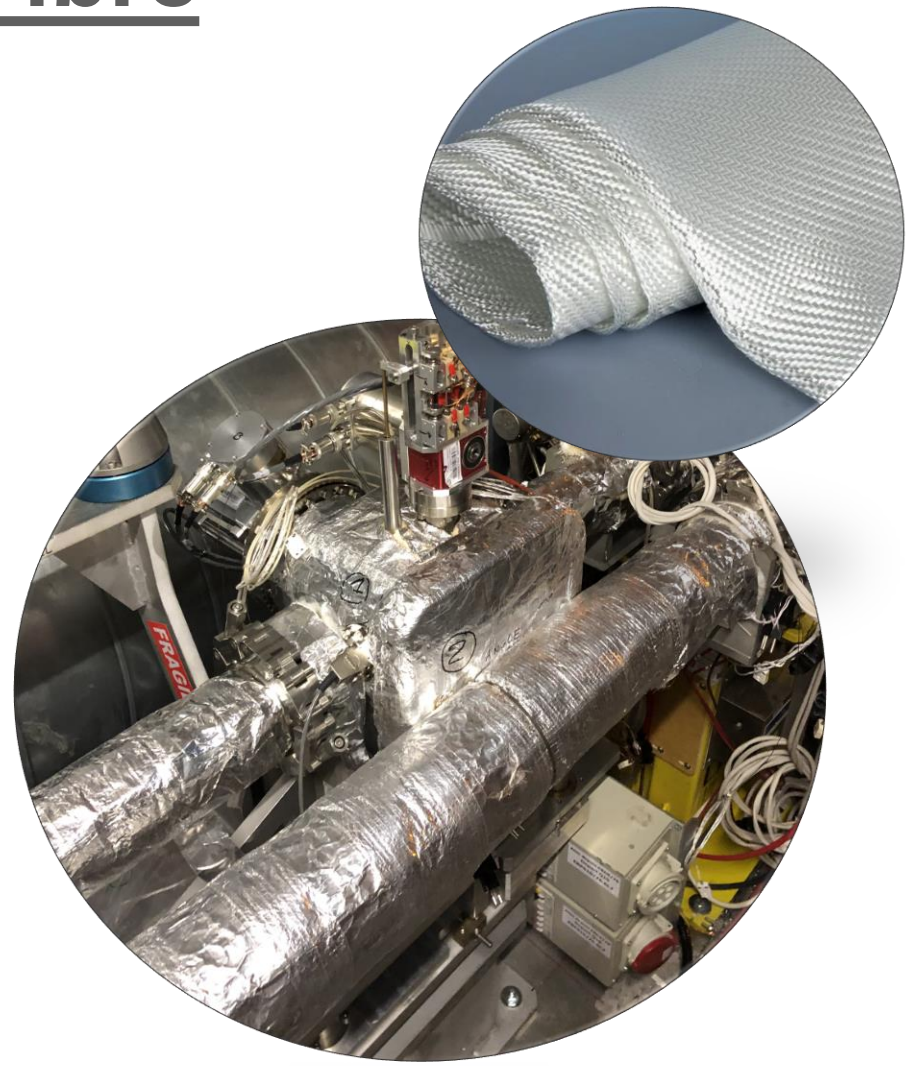


Glass/Mineral Fibre

- Thermal Conductivity Range: 0.035-0.045W/m.K

- Pros
  - Low thermal conductivity
  - Low cost
  - Easy installation

- Cons
  - Loose fibres
  - Irritant



Aerogels

- Thermal Conductivity (λ) Range: 0.015-0.025W/m.K

- Pros
  - Extremely low thermal conductivity
  - Thin
  - Lightweight
  - Hydrophobic
  - Flexible

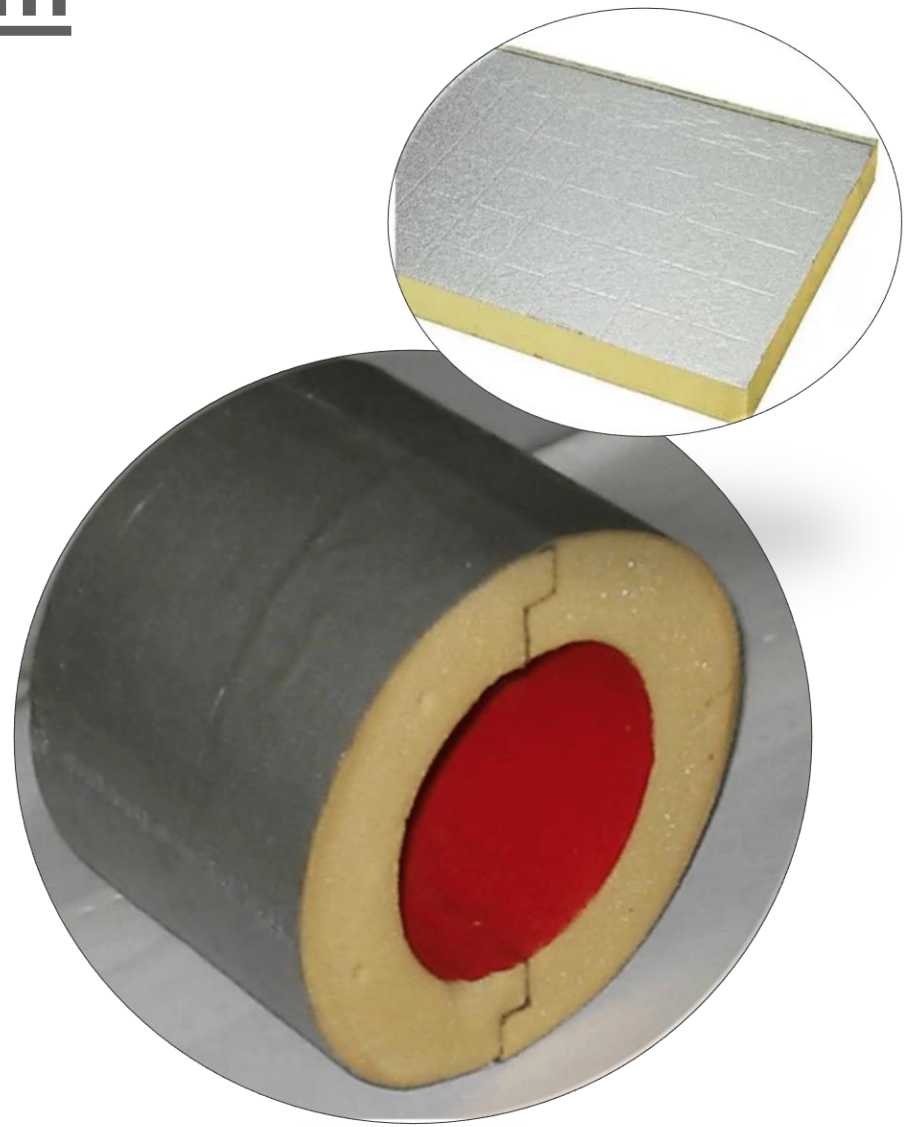
- Cons
  - Expensive
  - Brittle
  - Powdery debris
  - Irritant and possibility of respiratory problems

Polymer Foam

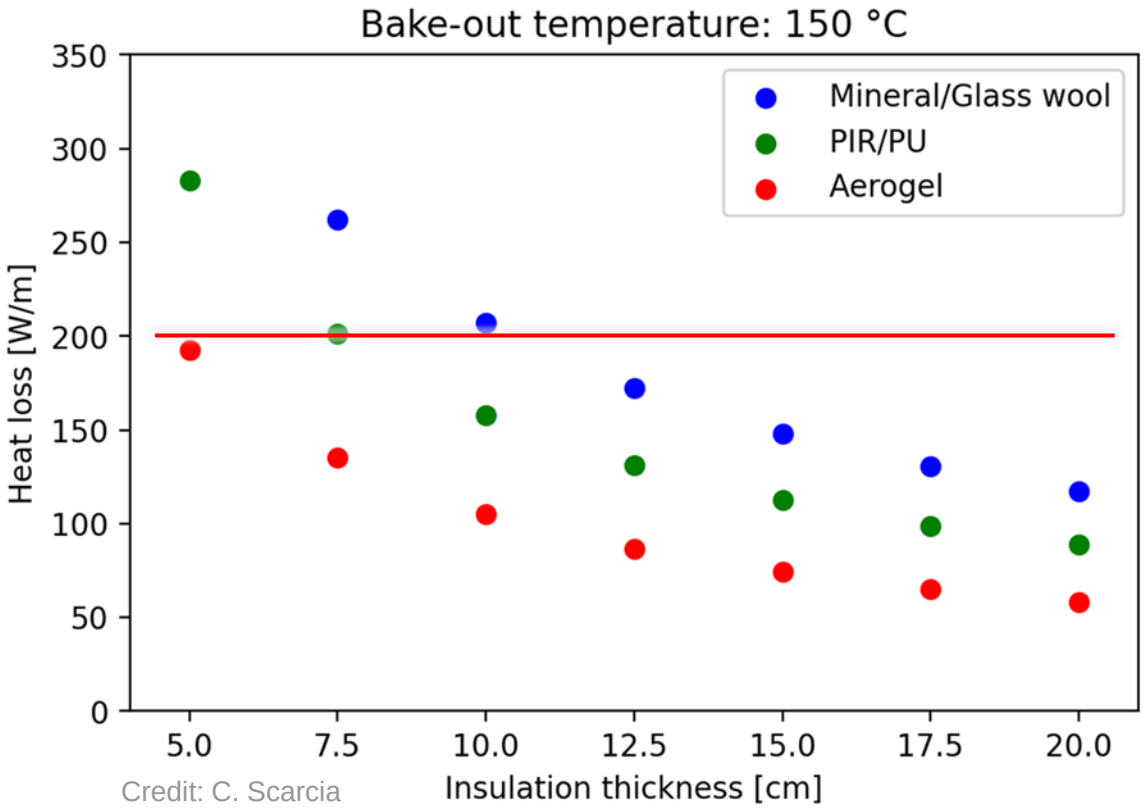
- Thermal Conductivity (λ) Range: 0.02-0.03W/m.K

- Pros
  - Very low thermal conductivity
  - Available in various thicknesses
  - Highly durable
  - lightweight

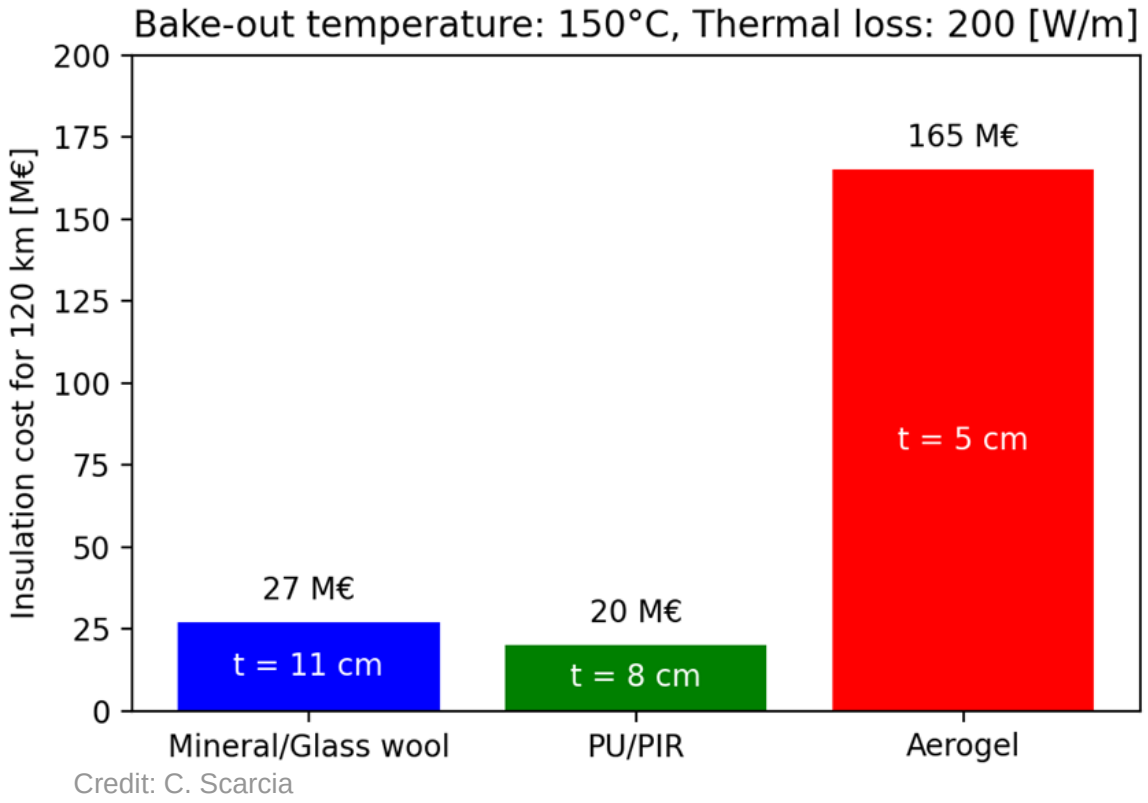
- Cons
  - More expensive than fibre-based materials
  - Off-gassing
  - Lower operating temperature



Insulation Impact on Heat Loss



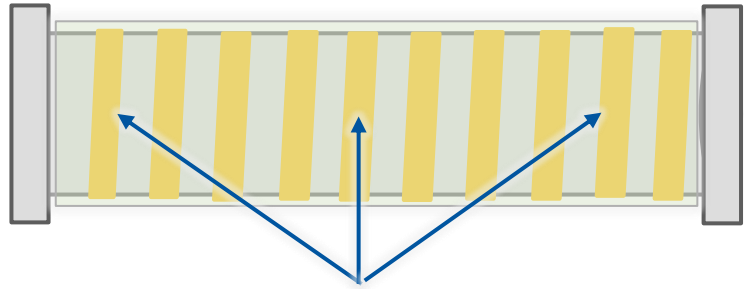
Credit: C. Scarcia



Credit: C. Scarcia

Lab 113 Tests

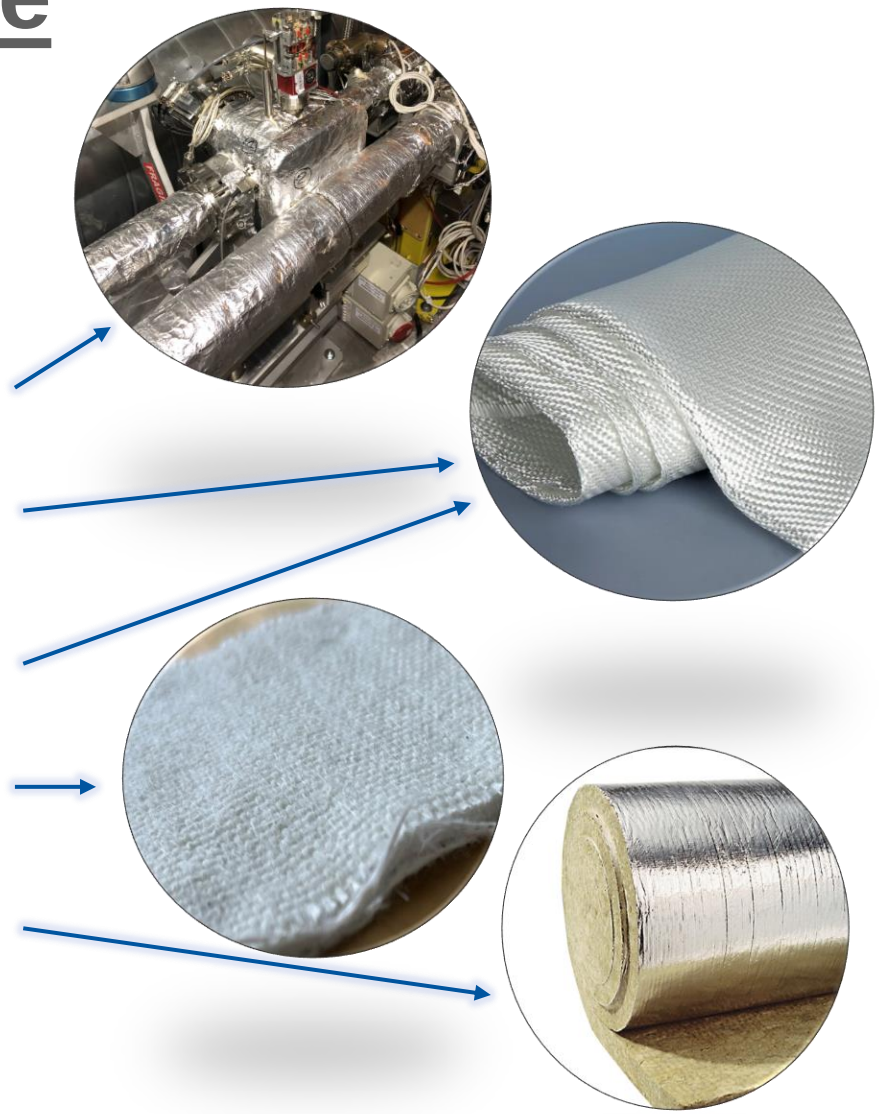
- Traditional heating using bands and collars
- Progressive bake-out cycle in 50°C steps
- Chamber temperature and external insulation temperature measured at 3 locations.
- Power consumption (Q) monitored at each step.



Thermocouple Locations

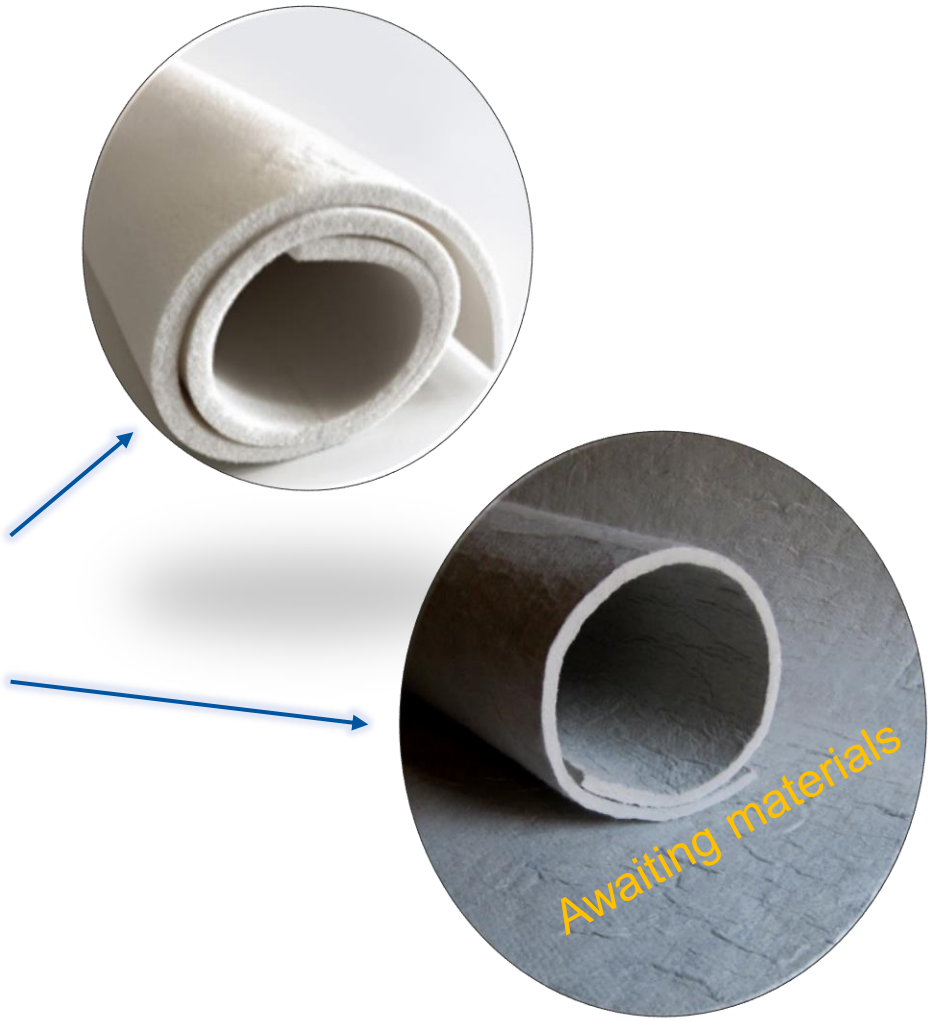
Glass/Mineral Fibre

Material	Supplier	Cost (€/m²)	Max °C	Thickness (mm)	λ @ 100°C (W/m.K)	R-Value (m².K/W)
Fibreglass w/ Aluminium	ELIT (FR)	€17.10	550	10	0.044	0.23
Glass Cloth [640g/m²]	ELIT (FR)	€18.00	500	2	0.050	0.04
Glass Cloth [920g/m²]	ELIT (FR)	€22.25	500	2	0.050	0.04
Fibreglass w/ glass cloth	ELIT (FR)	€29.40	550	10	0.045	0.22
Mineral Wool	SMI ISO (FR)	€19.78	650	30	0.046	0.65



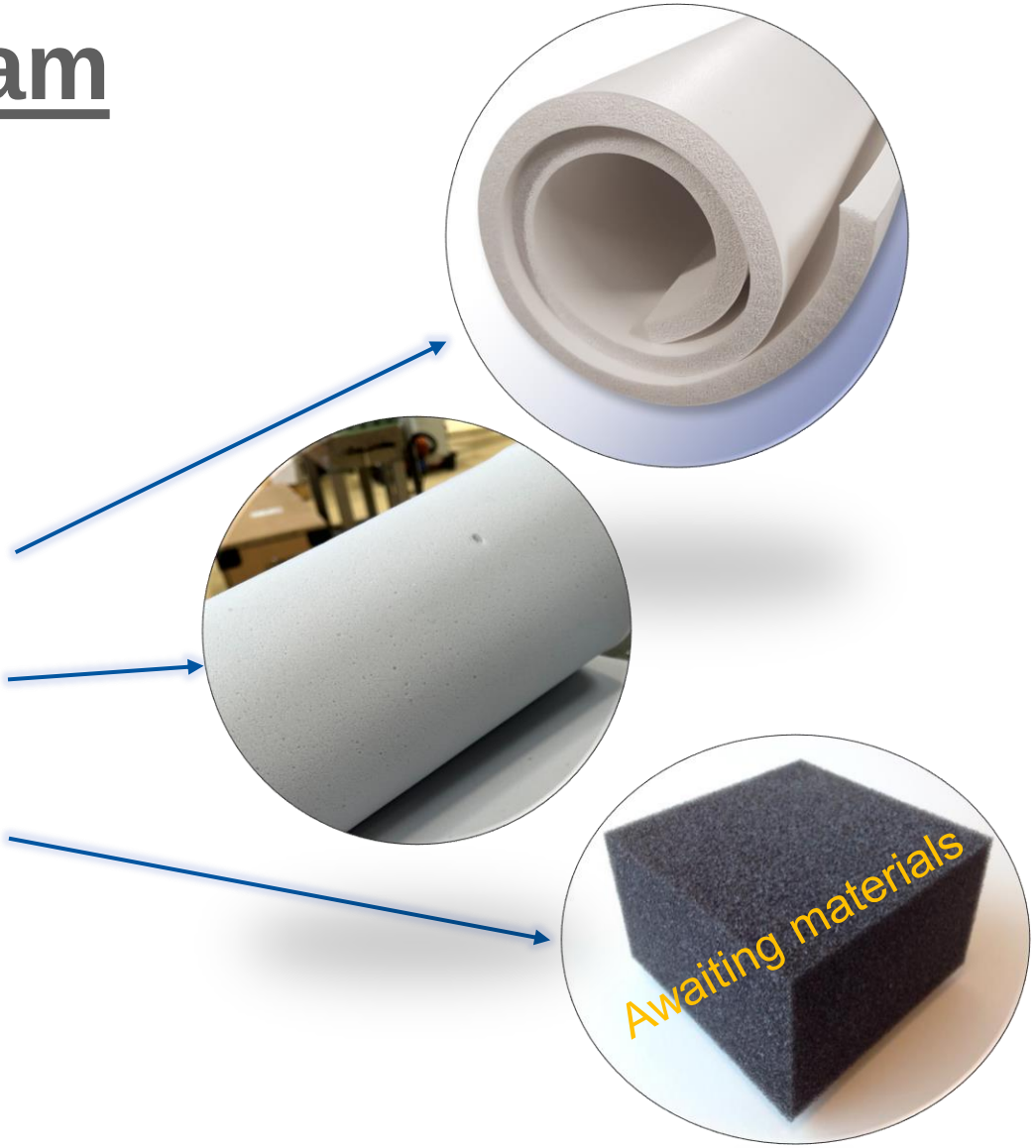
Aerogels

Material	Supplier	Cost (€/m²)	Max °C	Thickness (mm)	λ @ 100°C (W/m.K)	R-Value (m².K/W)
Pureflex	AGITEC (CH)	€85.00	150	10	0.016	0.63
Pyrogel	Aspen Aerogels (US)	-	650	5	0.023	0.22



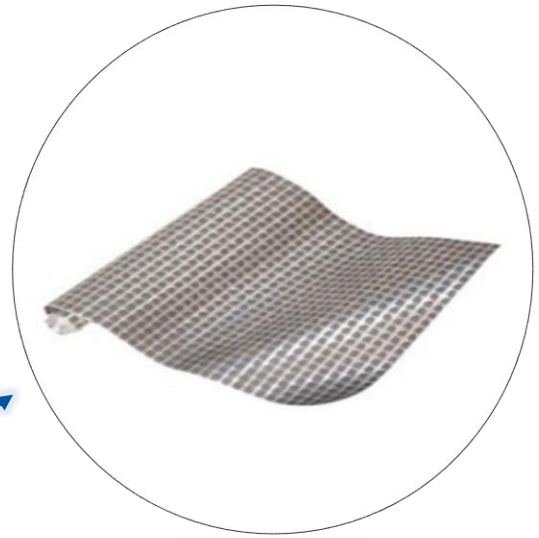
Polymer Foam

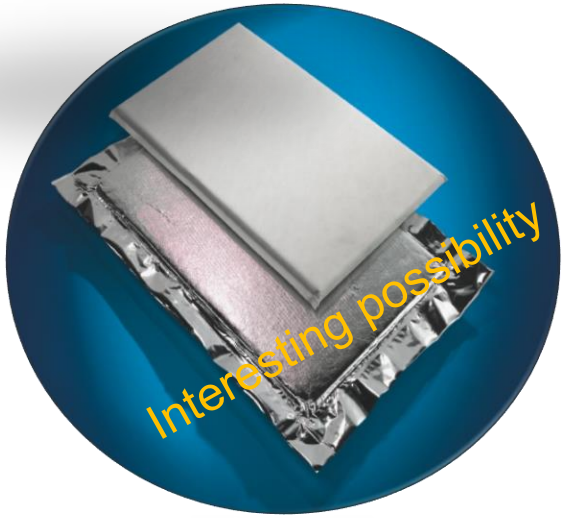
Material	Supplier	Cost (€/m²)	Max °C	Thickness (mm)	λ @ 100°C (W/m.K)	R-Value (m².K/W)
Silicone Foam	ELIT (FR)	€300.00	230	10	0.021	0.48
Aminoplastic Foam	ELIT (FR)	€44.52	650	10	0.023	0.43
Polyurethane Foam	-	-	150	-	0.02-0.03	-



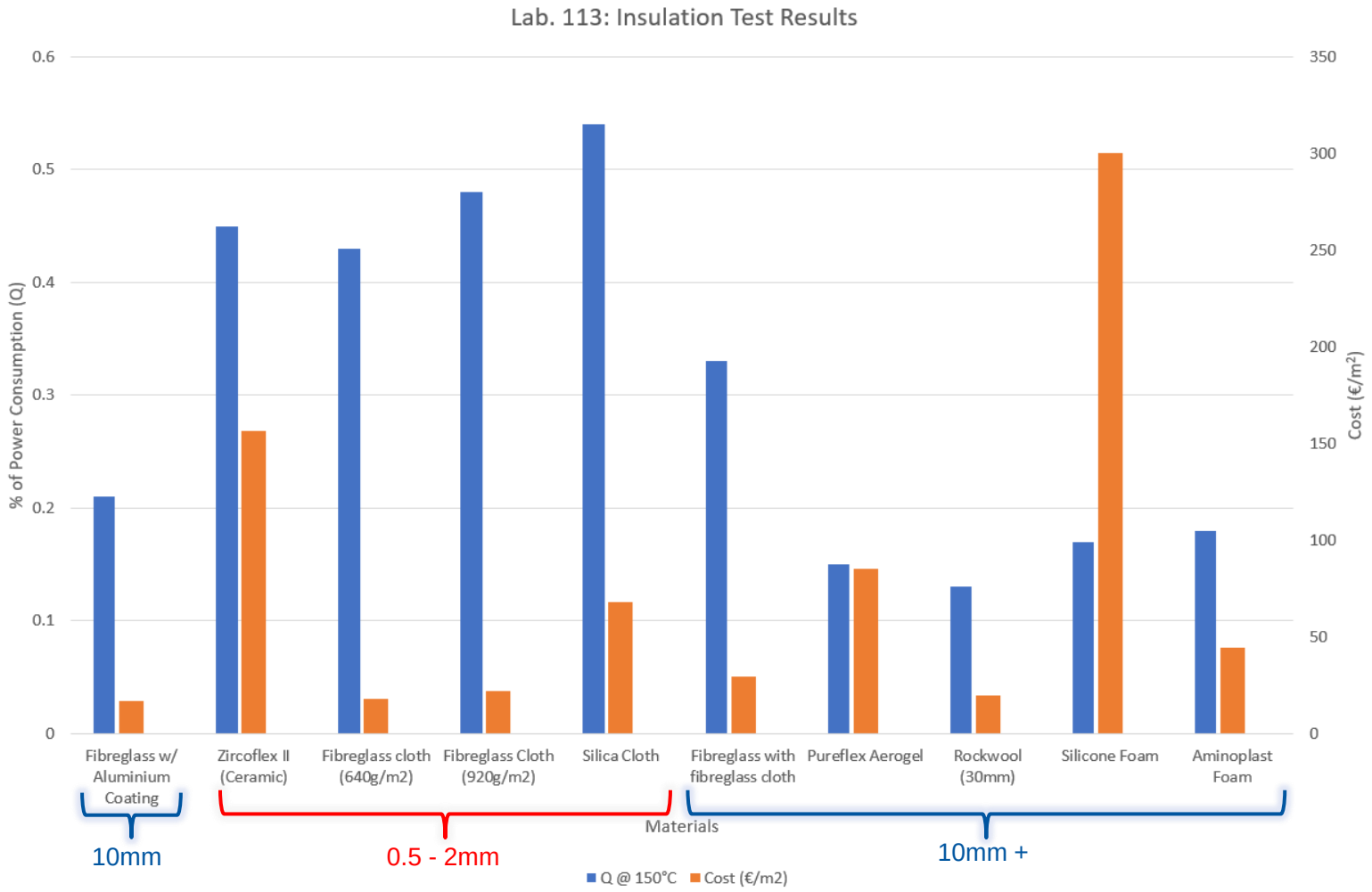
Additional options

Material	Supplier	Cost (€/m²)	Max °C	Thickness (mm)	λ @ 100°C (W/m.K)	R-Value (m².K/W)
ZircoFlex	Zircotec	€156.30	500	0.5	0.018	0.16
Vacuum Insulation Panels	VA-Q-TEC	-	130	-	0.0035	-





Power Consumption Vs Cost

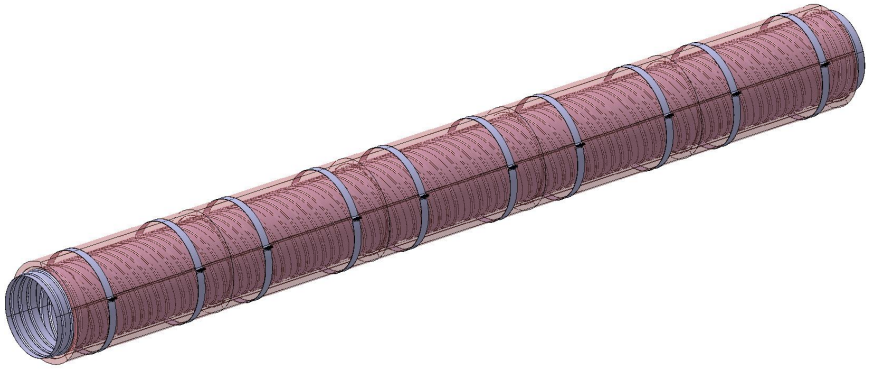


Final considerations

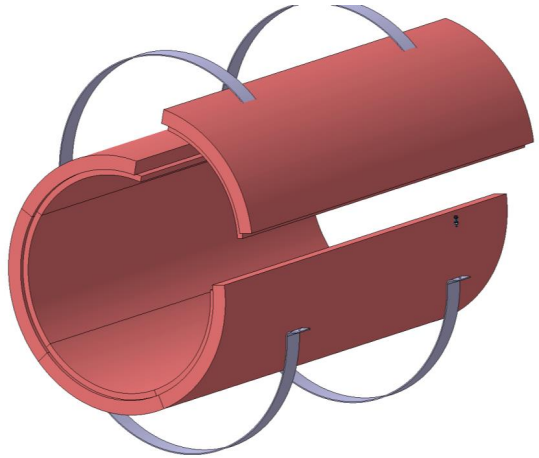
- Research ongoing, but for now, PU foam is first choice.
- Does additional processing of PU foam to custom-made shells negate energy savings?
- Will the bake-out be completed in one cycle or done in sectors?
- In addition to raw material costs, transport, storage and manpower costs must be taken into account.

Next Steps

- Continue to source alternative insulation materials to test.
- Source insulating plates for ET pilot sector assembly.
- Test and implement Joule effect heating system.



Credit: L. Gentini



Thank you
for your attention

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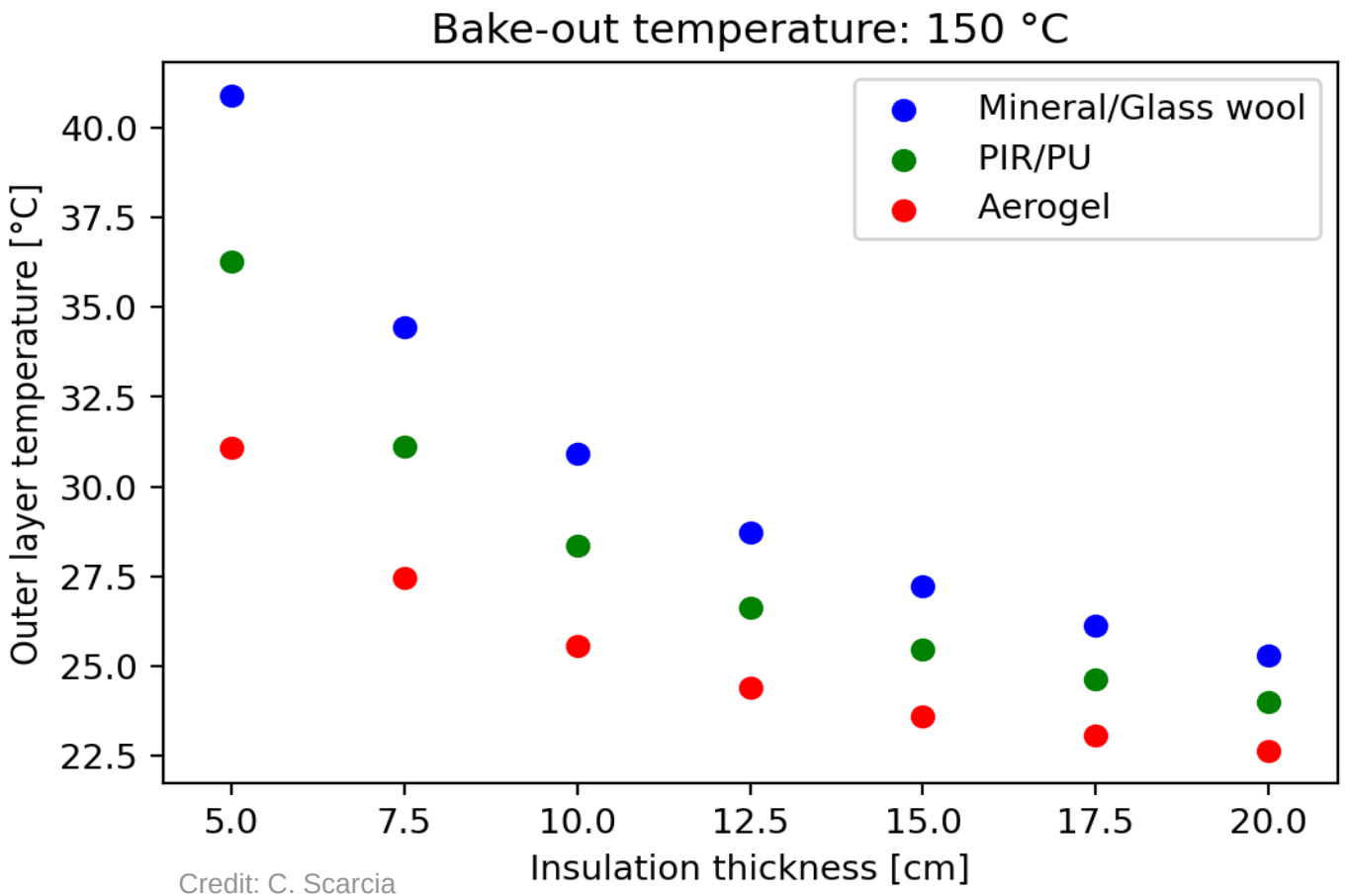
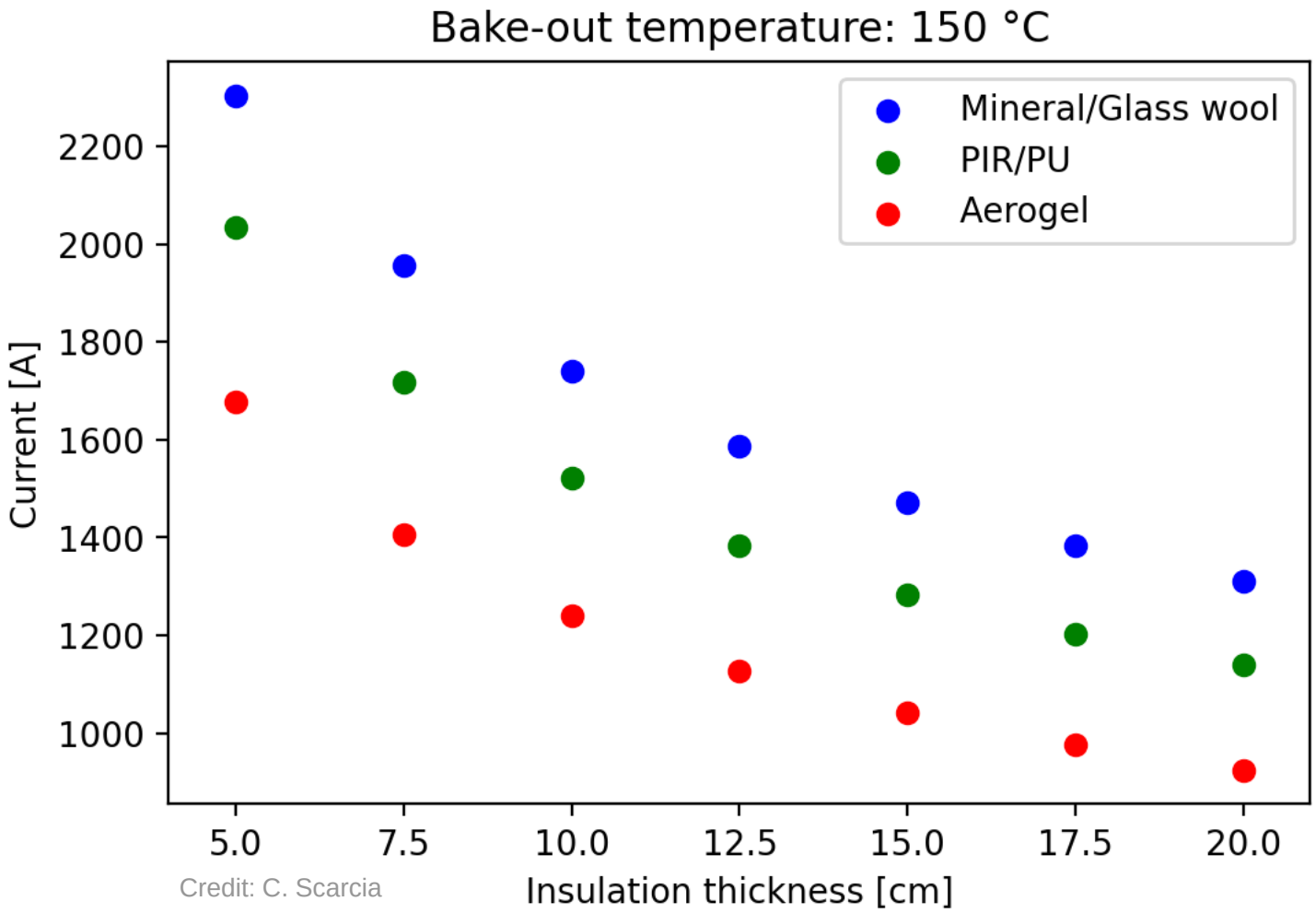
Insulation Thickness Vs External Temperature



Credit: C. Scarcia

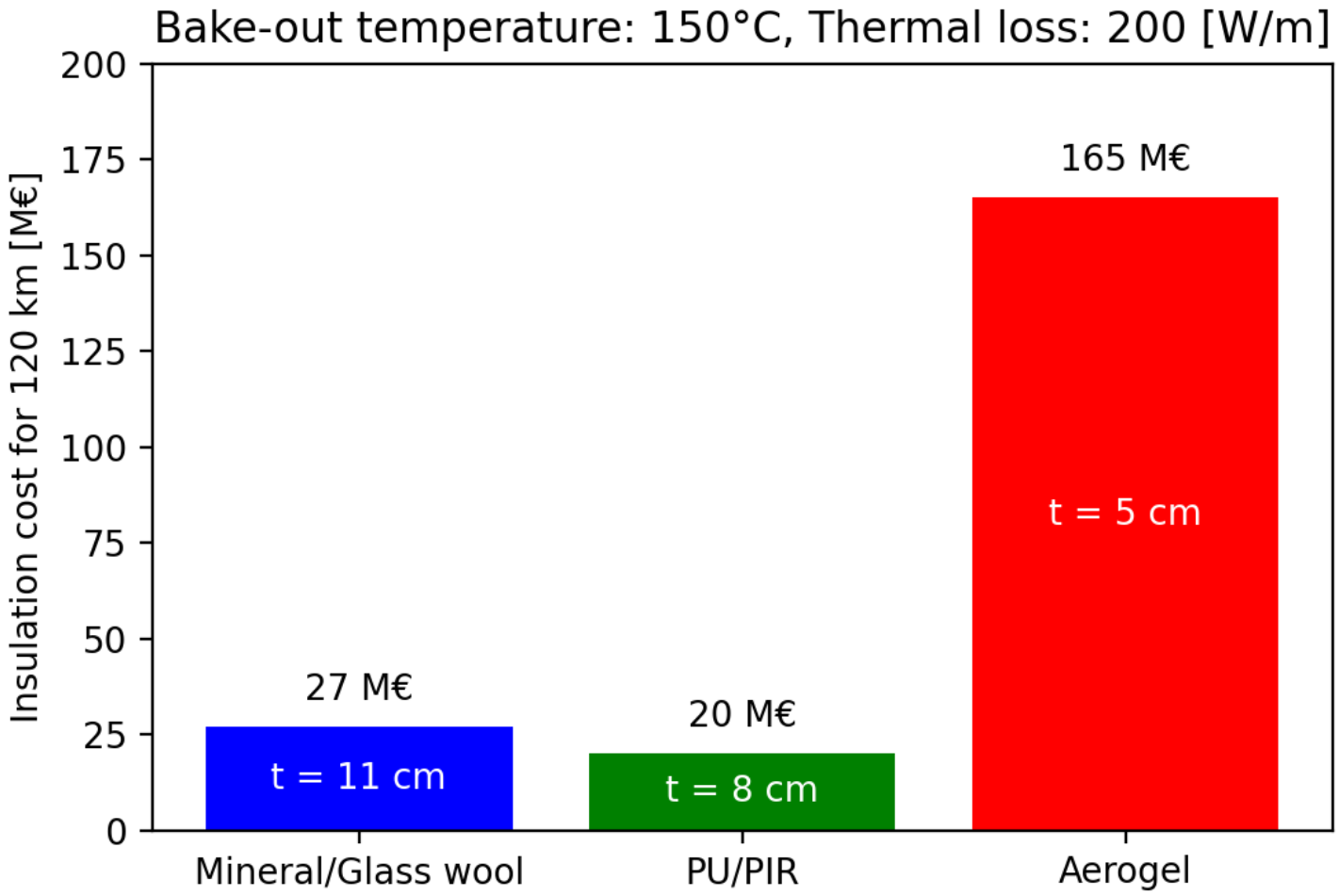
Current Vs Insulation Thickness



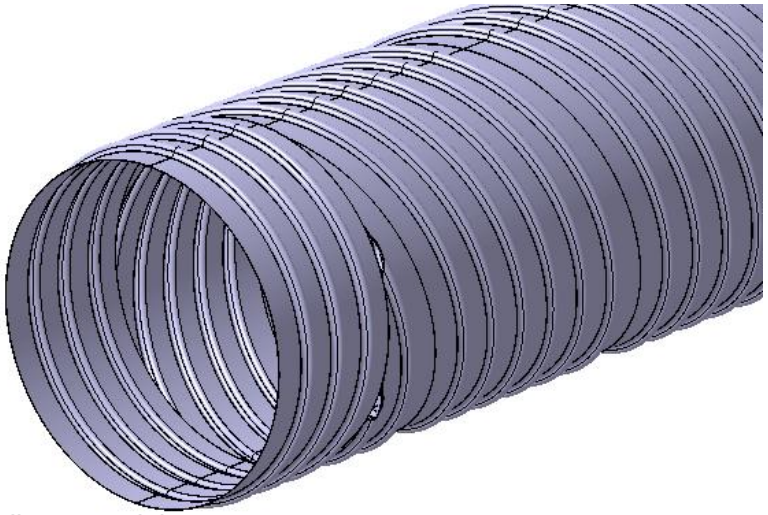
Credit: C. Scarcia

Cost Estimation

Thermal loss limit of 200W/m applied to calculate the required insulation thickness and cost of materials.



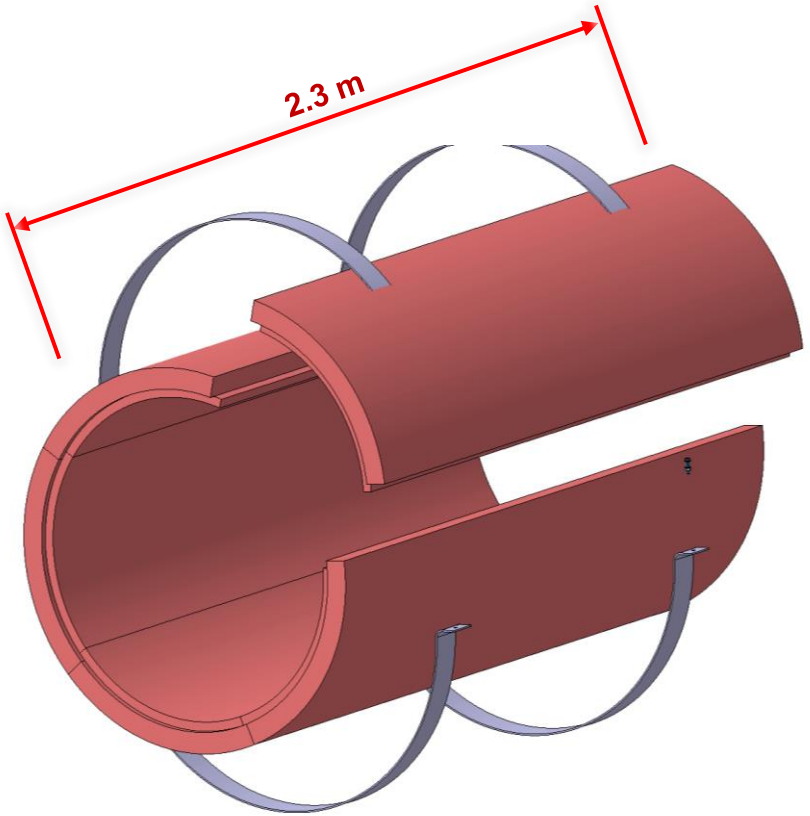
Pipe sector



PRELIMINARY DESIGN

Rolled and welded pipe with preformed 860 mm width sheet.

- Pipe length : 12 m
- Diameter : 1 m
- Thickness: 2 mm
- Wave high: 25 mm
- Pitch : 125 mm



Five sectors of insulating plates

- Length : 2.3 m
- Thickness: 100 mm

Credit: L. Gentini