Cost assessment guidelines

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29th of March 2023

Introduction

Cost estimate:

- ❑ Cost drivers
- ❑ Basics for a cost estimate
- ❑ Contributions of a GWT
- ❑ Optimization
- ❑ Sensitivity analysis
- ❑ Summary

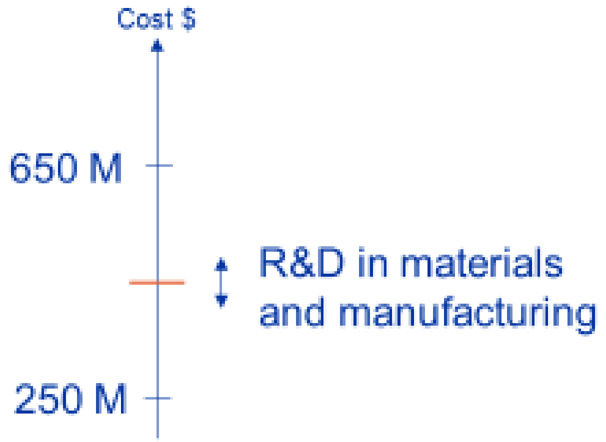
The ET beampipe baseline: cost estimation

Scaling of the:

- VIRGO vacuum costs to ET leads to 550 M€, 1/3 of the total proposed budget.
- LIGO vacuum costs to CE leads to 650 M$, more that 50% of the total proposed budget.

Cost of gas pipelines of equal length (lowest envisaged cost):

- 250 M$ (estimation by Rainer Weiss)



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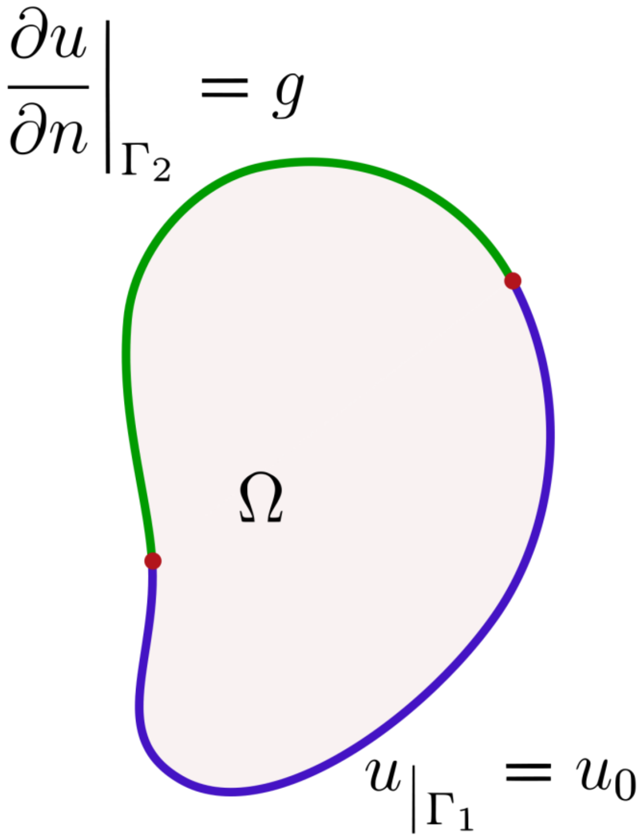
Cost drivers

- To evaluate the cost ==> treat several interlinked problems (Define WBS)
- First cost estimate ==> identify cost drivers
- For each unit we have to identify:
  - Boundary conditions (i.e. tunnel or surface, time)
  - Variables that set different scenarios (i.e. material choice, thickness)
  - Parameters for optimization (i.e. insulation thickness, bakeout temperature, etc.)



One variable in a WBS can become a boundary condition of another one ==> Keep an updated global view

Comprehensive

- **All life** costs (evaluate operation costs during lifetime of the facility)
- WBS product oriented
- Document all assumptions

Well Documented

- Documents all sources, and methodology
- Technical baseline is consistent with the cost estimate

Reliable cost estimate

Accurate

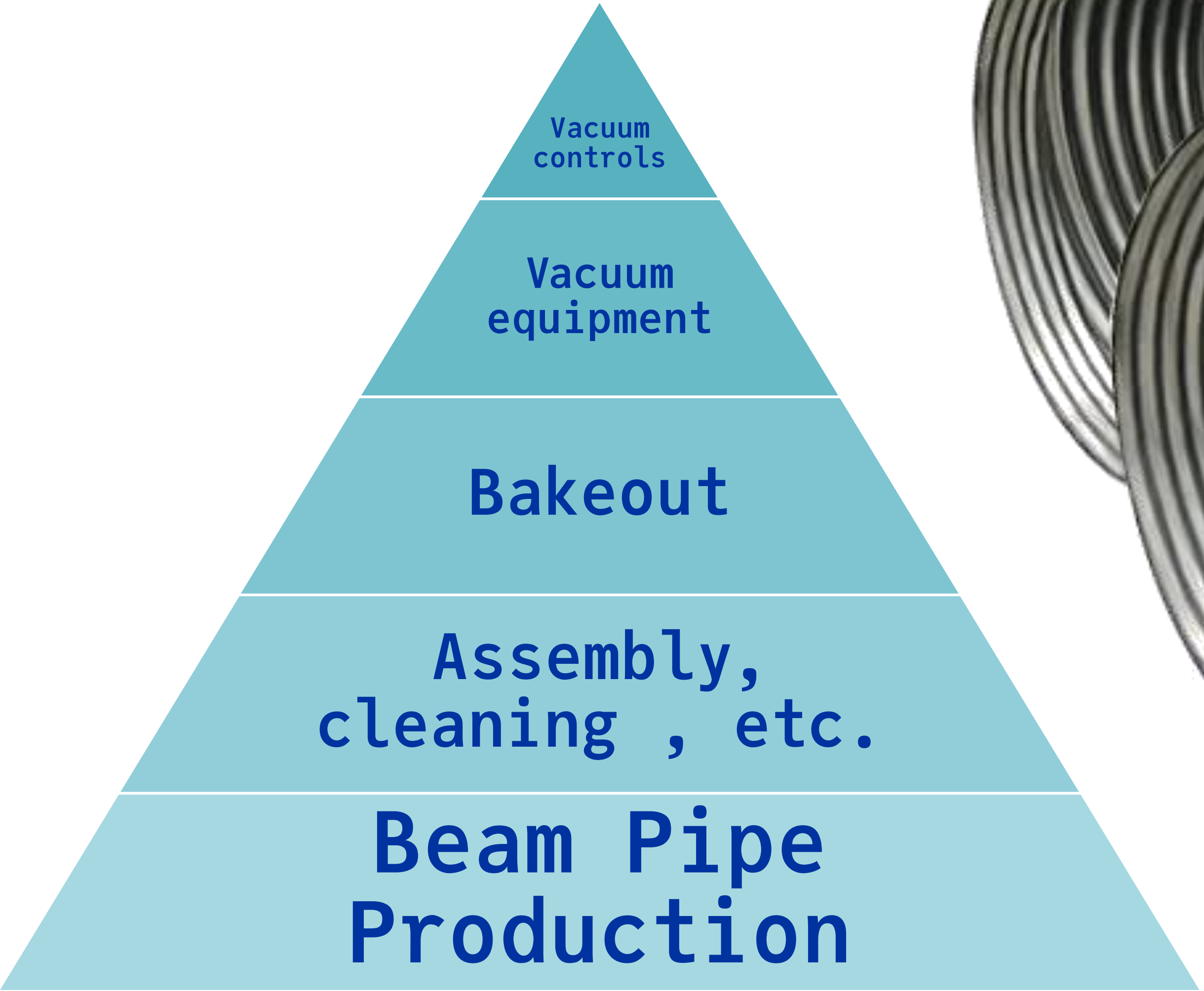
- Based on models estimating each WBS element
- Adjusted to inflation
- Regularly updated
- Based on past cost estimates

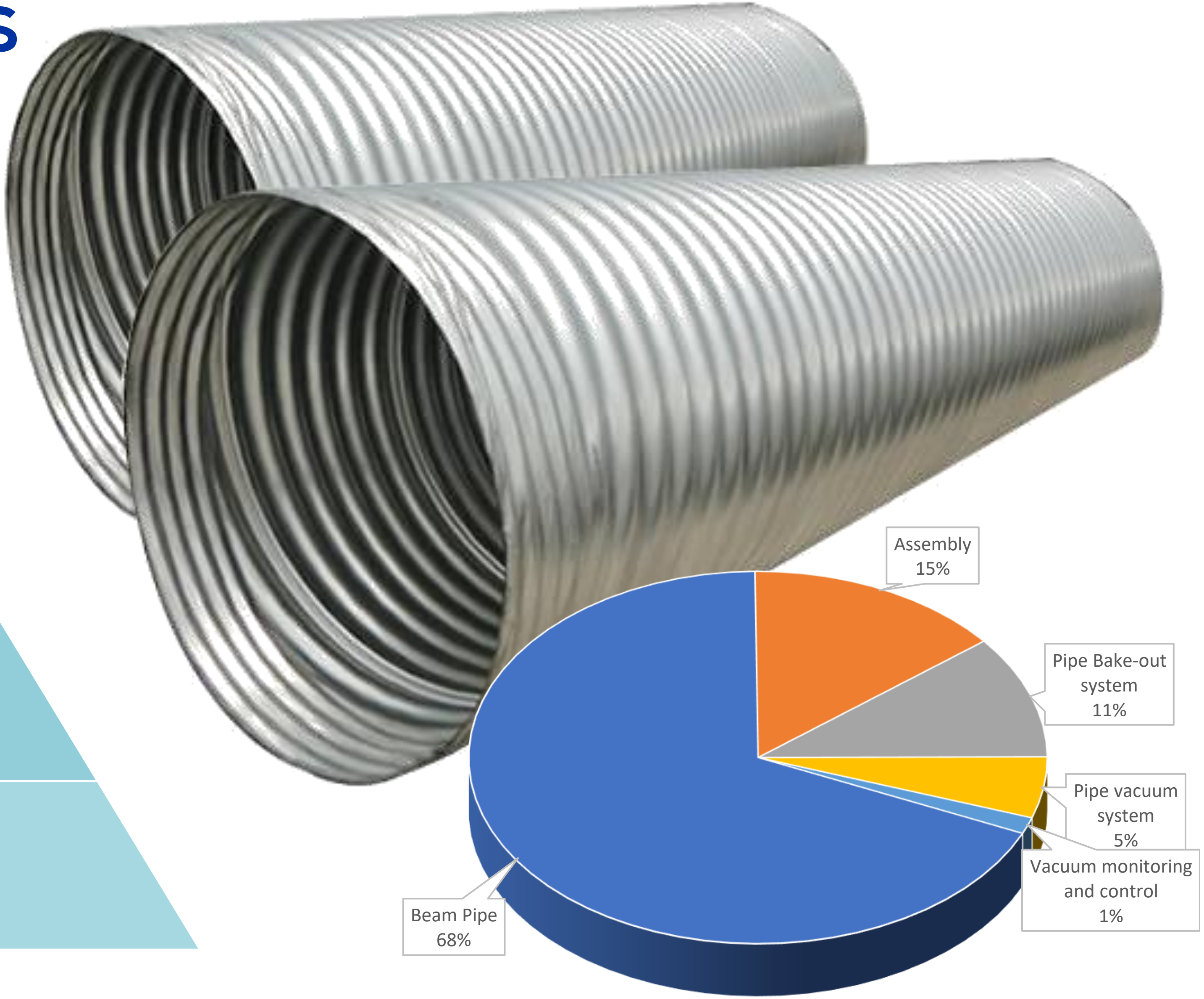
Credible

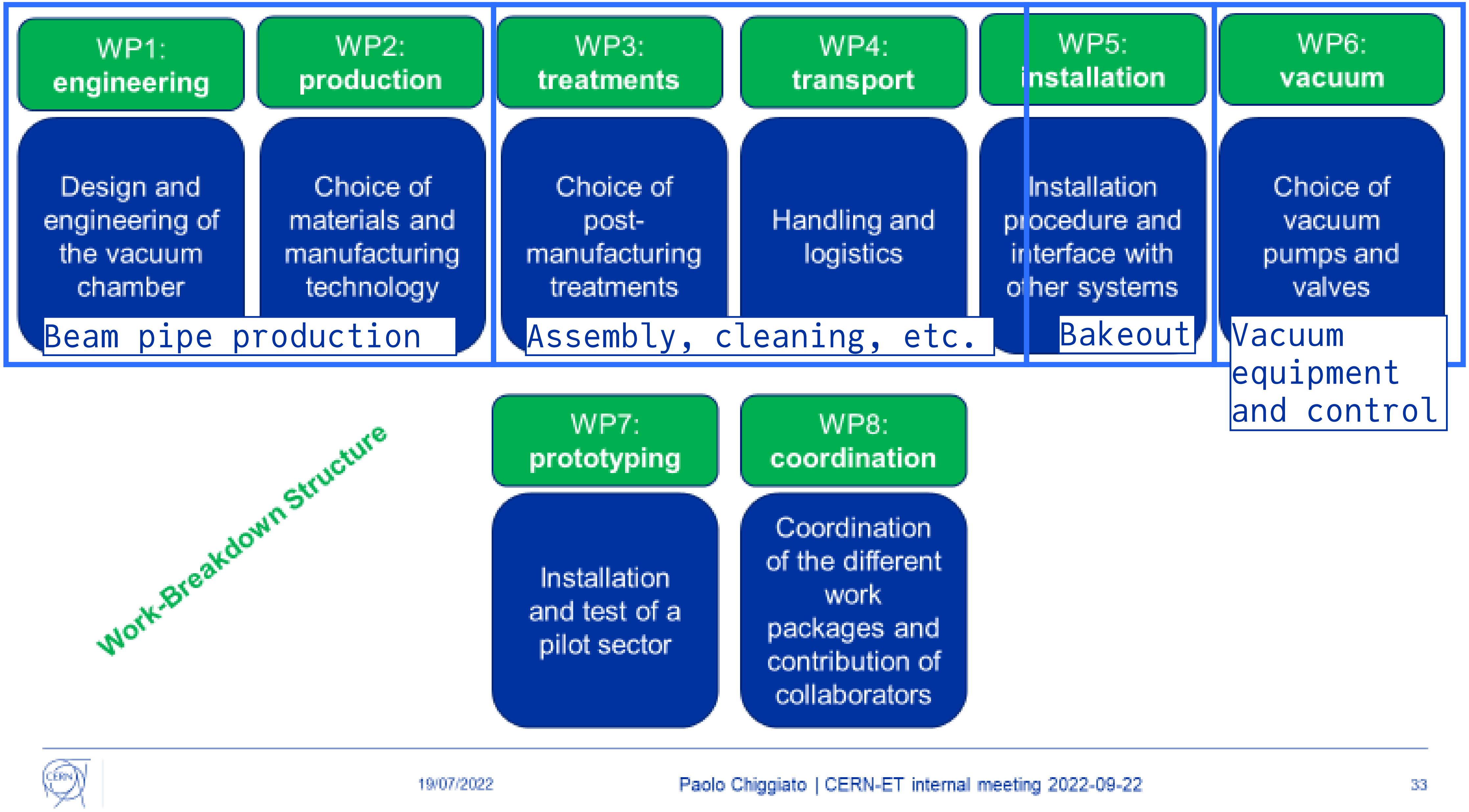
- Includes sensitivity analysis
- Includes risk analysis (and mitigations)
- Includes cross checks (other methodologies)

From [3]

Cost contributions






WP1: engineering
Design and engineering of the vacuum chamber
WP2: production
Choice of materials and manufacturing technology
Beam pipe production
WP3: treatments
Choice of post-manufacturing treatments
WP4: transport
Handling and logistics
Assembly, cleaning, etc.
WP5: installation
Installation procedure and interface with other systems
Bakeout
WP6: vacuum
Choice of vacuum pumps and valves
Vacuum equipment and control
WP7: prototyping
Installation and test of a pilot sector
WP8: coordination
Coordination of the different work packages and contribution of collaborators
Work-Breakdown Structure
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33

Beam pipe production

Boundary conditions:

- ❑ Tunnel or surface? ==> Logistics!
- ❑ In situ or remote production ==> Logistics!
- ❑ Tube dimensions

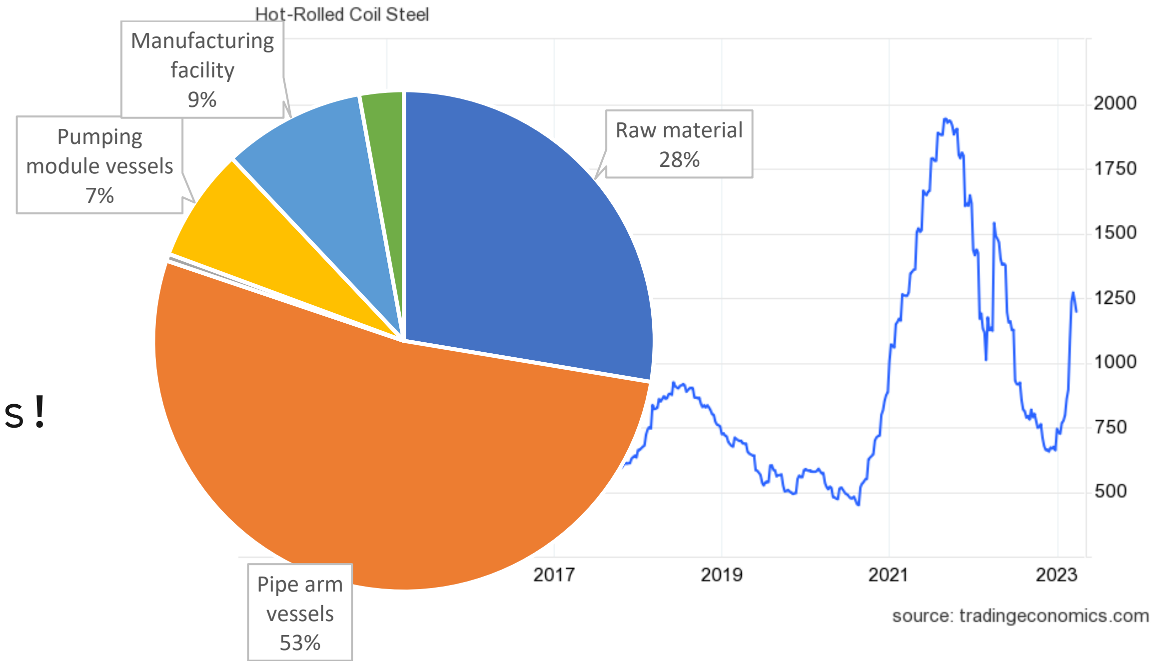
Constrains to logistic, transport and installation

Variables:

- ❑ Material (Stainless steel, mild steel, etc.)
- ❑ Thermal treatment of raw material?
- ❑ Production method (spiral welding, longitudinal welding, etc.)

Parameters:

- ❑ Thickness and shape (thin corrugated, thick with reinforcement, thick straight)



Assembly, cleaning and leak detection

Boundary conditions:

- ❑ Tunnel or surface?
- ❑ In situ or remote production
- ❑ Pipe dimensions, material and thickness
- ❑ Production method

Variables:

- ❑ Transport and handling in final position
- ❑ Support structure and alignment
- ❑ Cleaning method
- ❑ Helium leak detection method

Parameters:

- ❑ Separation between supports
- ❑ Cleaning conditions, time for cleaning
- ❑ Leak detection strategy

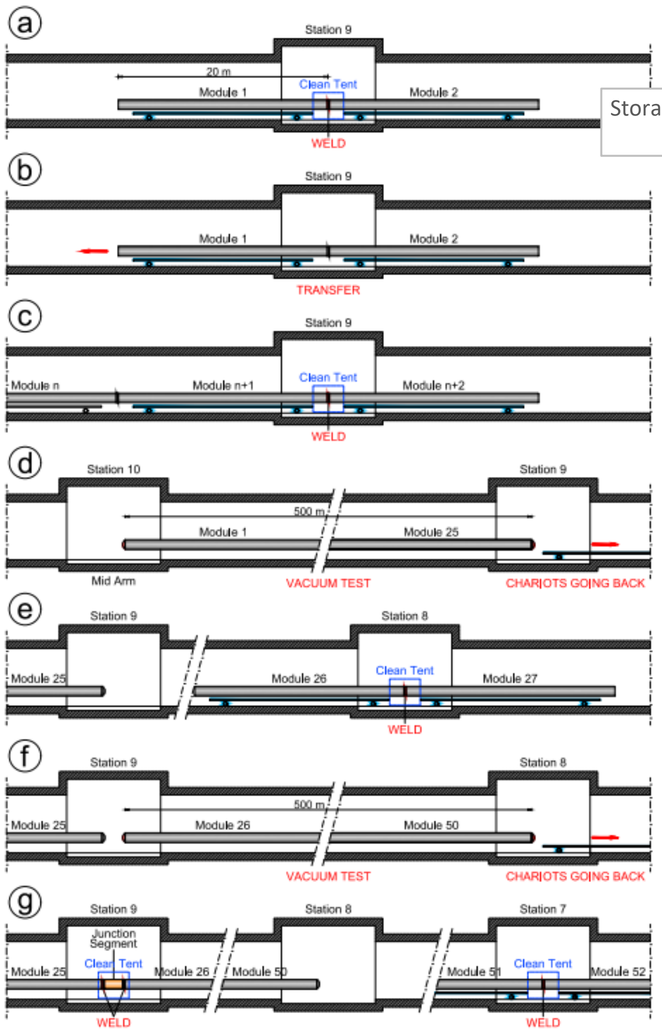
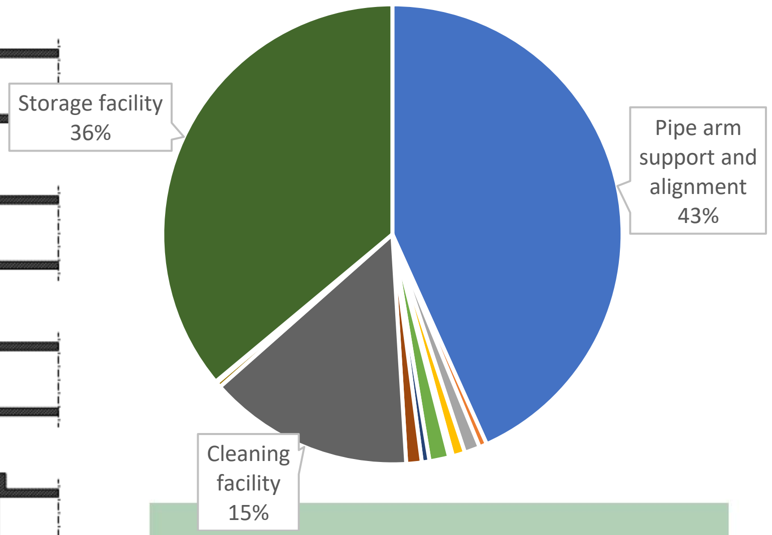


Figure 6.23: The assembly sequence of one vacuum pipe.



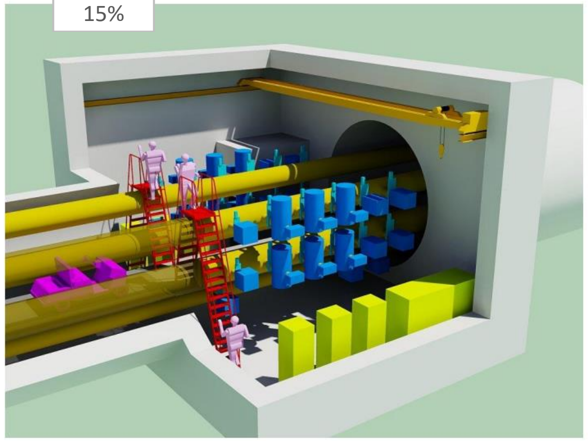


Figure 6.22: 3D view of a pumping station: the blue objects represent the pumps and sensors, the yellow ones the cabinets for pumps control and baking power supply (1 cabinet for all). A separate small room is reserved for the high voltage electrical transformer.

Bakeout

Boundary conditions:

- ❑ Tunnel or surface?
- ❑ Pipe dimensions, material and thickness
- ❑ Maximum available heating power

Variables:

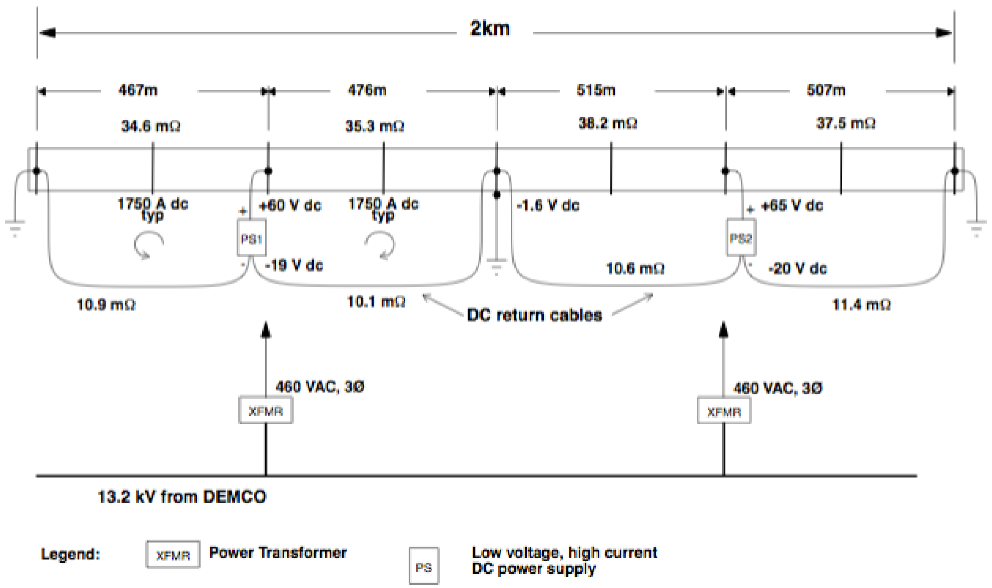
- ❑ Type of pumping
- ❑ Type of insulator
- ❑ Heating power distribution

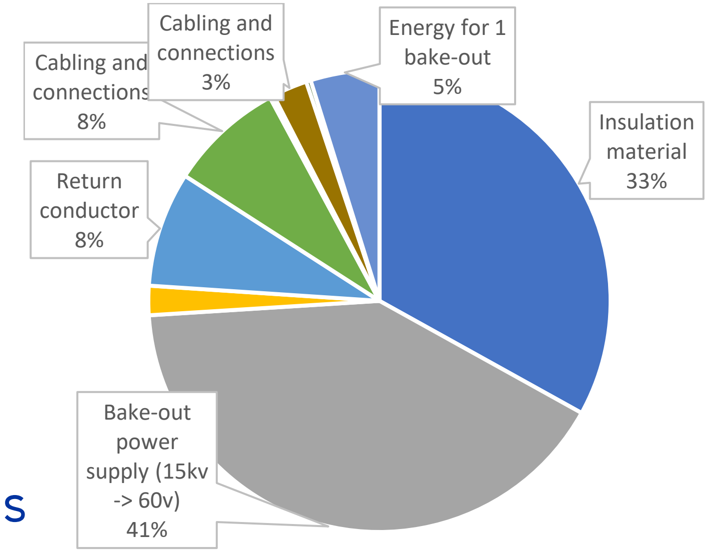
Parameters:

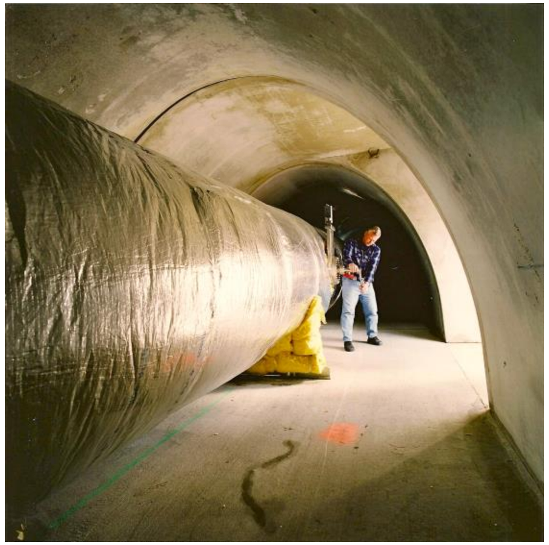
- ❑ Bakeout time
- ❑ Bakeout temperature
- ❑ Water Pumping speed and distribution
- ❑ Insulator thickness

Cost driven by insulator and power supplies

BEAM TUBE BAKEOUT ELECTRICAL HEATING POWER







Vacuum equipment and control

Boundary conditions:

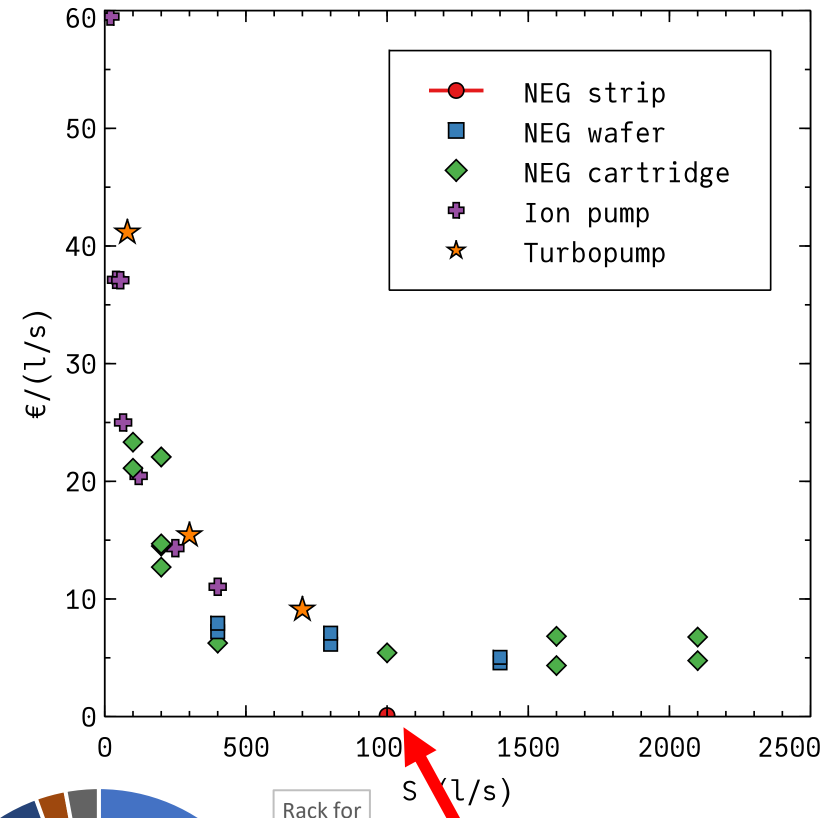
- ❑ Defined by the previous units
- ❑ Pumping layout and control are defined together

Variables:

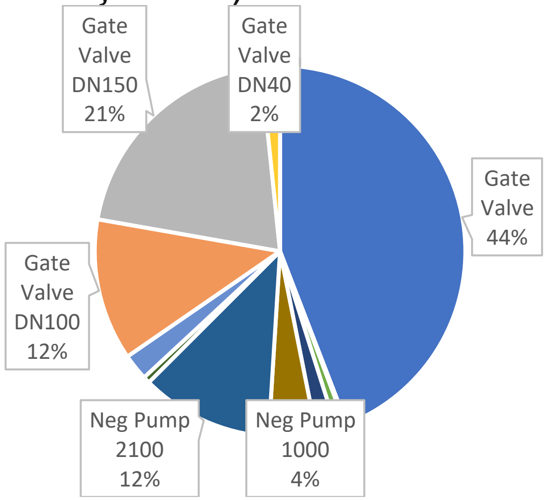
- ❑ Bakeout parameters
- ❑ Type of pumping and distribution (H_2, CH_4, CO, etc.)
- ❑ Valve sectorization
- ❑ Instrumentation (type, distribution, etc.)

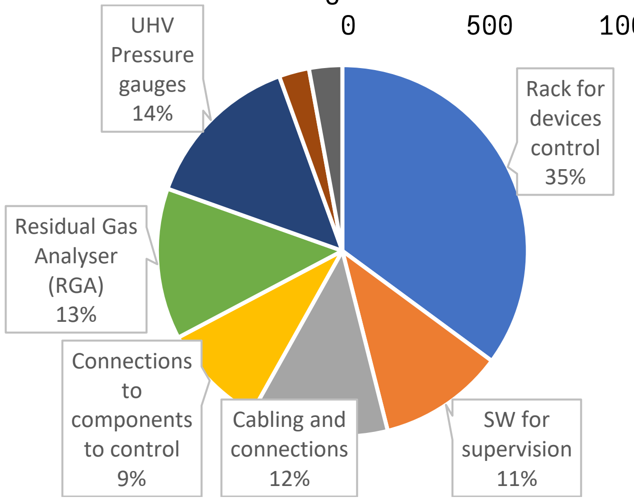
Parameters:

- ❑ Pumping speed
- ❑ Pump distribution



NEG strips



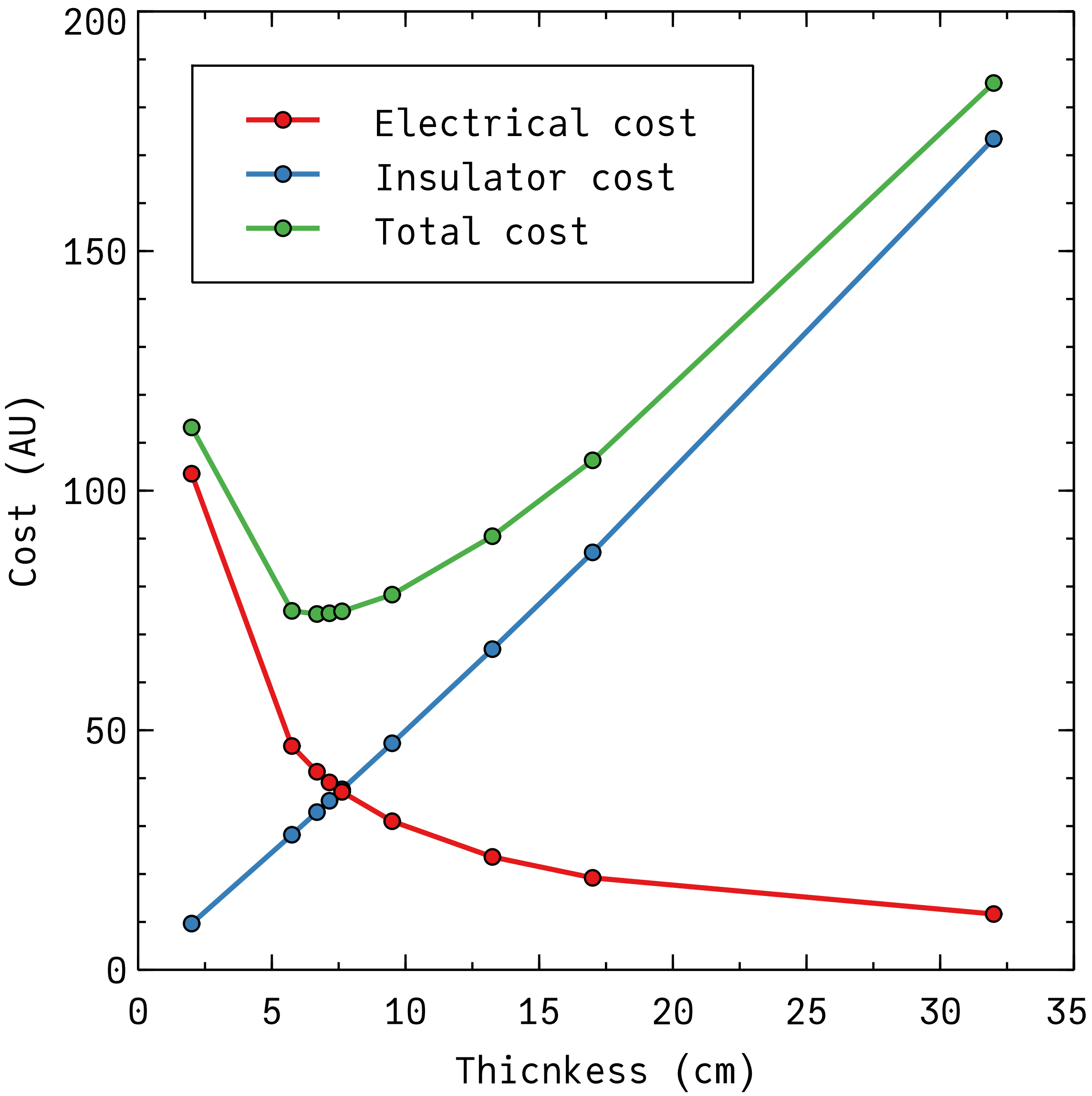


Optimization

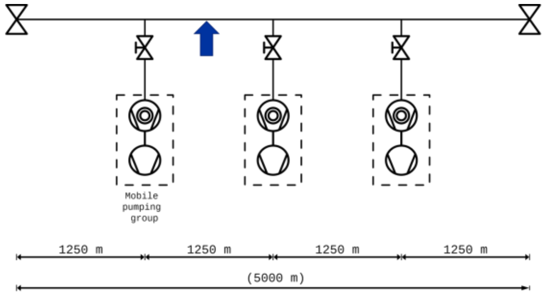
Problem: Optimization with multiple parameters

The same physical models used for the design, can be integrated for cost optimization

Example ==> multiparametric bakeout optimization

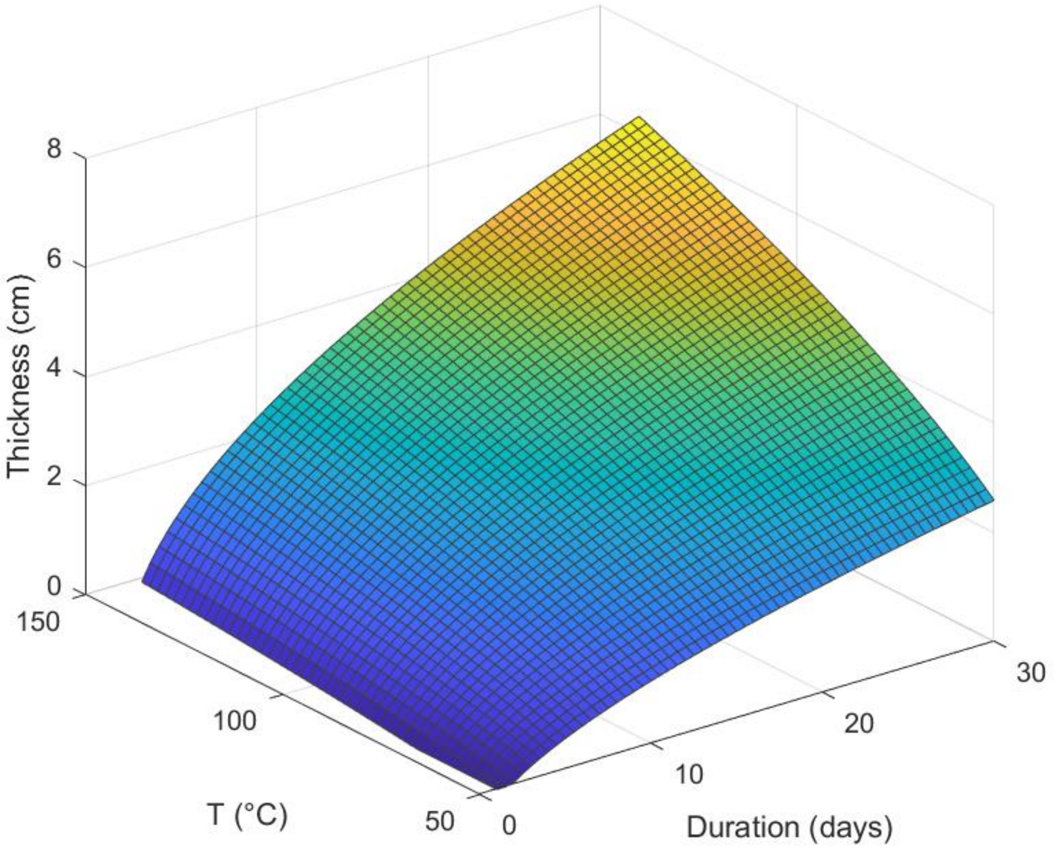


Example: Bakeout optimization



- Thermal conductivity 35 mW/m/K
- Tube 4 mm wall
- For each temperature and bake-out duration
  ==> Optimum thickness to minimize the cost

Cost = (Electrical cost to reach baking temperature) +
(Electrical cost during bakeout) +
(Insulation cost)



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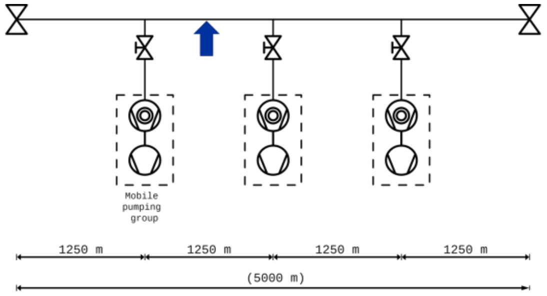

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Cost = (Electrical cost to reach baking temperature) +
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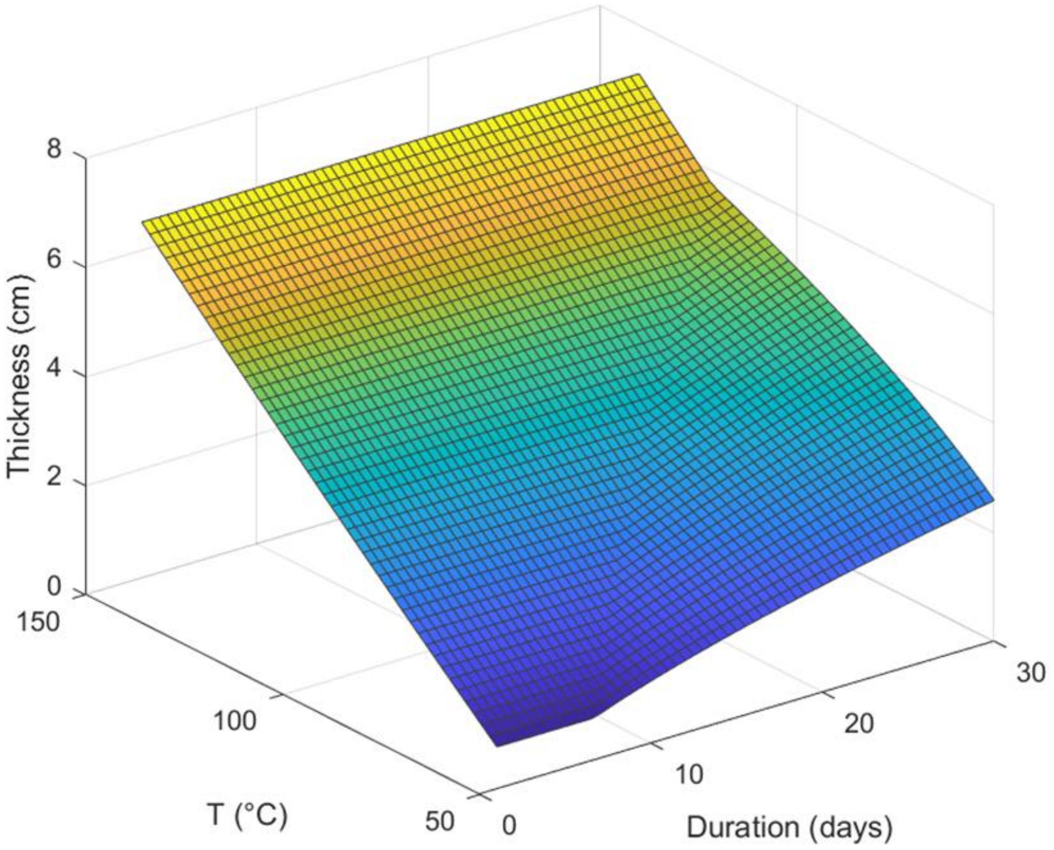
- No limit to the power consumption ==> Limited to <200 W/m



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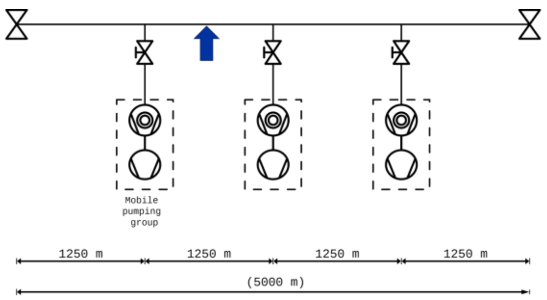

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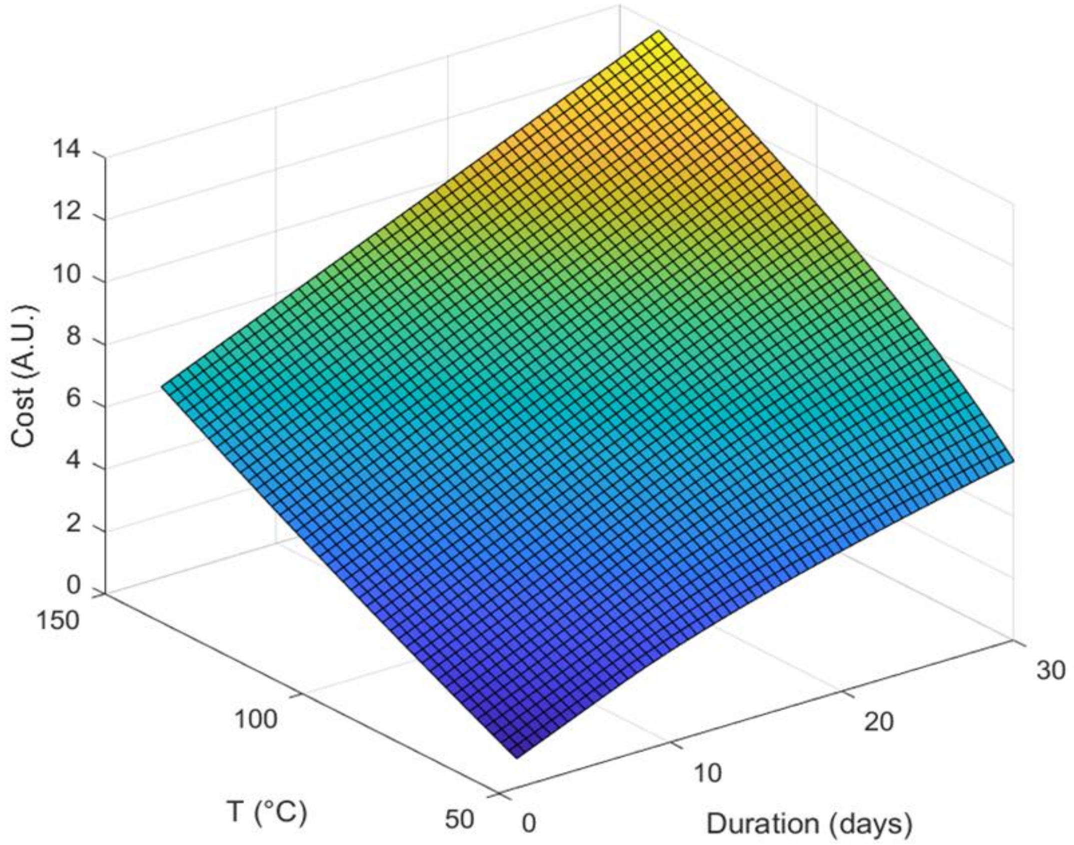

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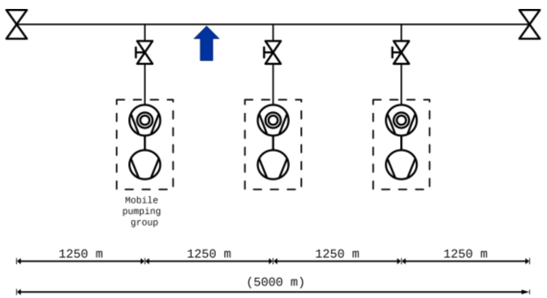
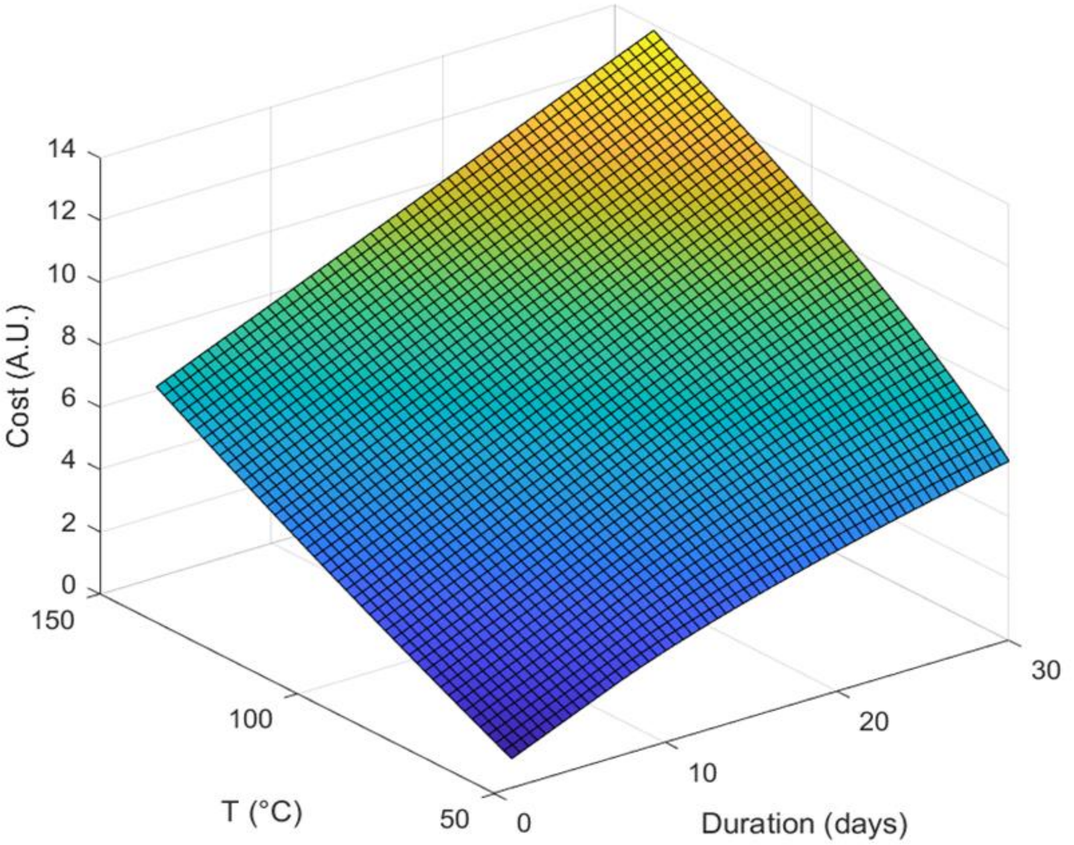


- Thermal conductivity 35 mW/m/K
- Tube 4 mm wall
- For each temperature and bake-out duration ==> Optimum thickness to minimize the cost

Cost = (Electrical cost to reach baking temperature) +
(Electrical cost during bakeout) +
(Insulator cost)

- No limit to the power consumption ==> Limited to <200 W/m
- But not all combinations are good ==> Limited to max(P)<2×10^{-11} mbar
- Configuration NEG cartridges 1500 l/s every 625 m and turbos every 1250 m
- 1D model using Temkin isotherm



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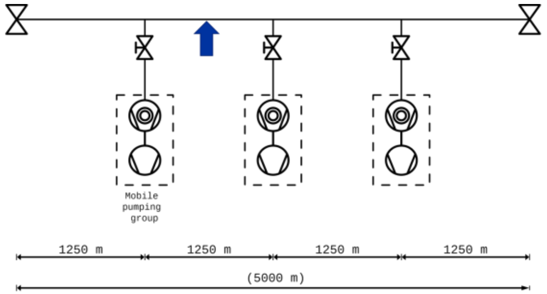
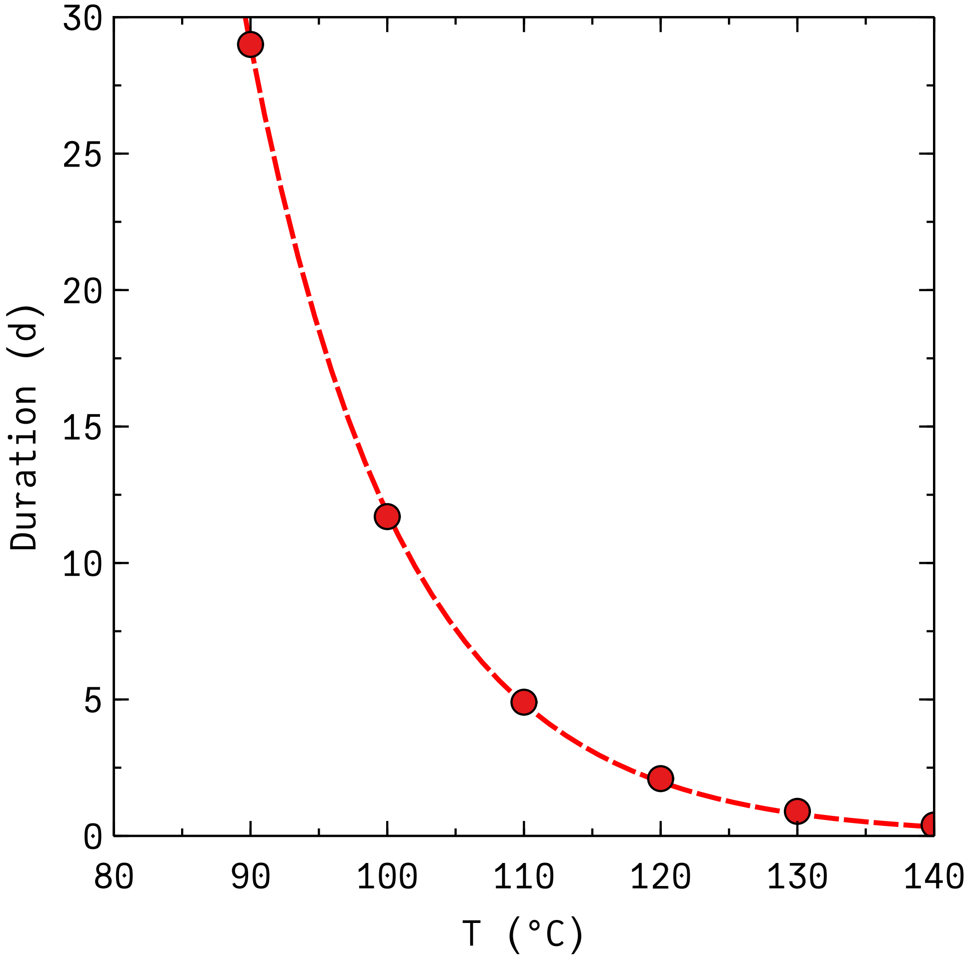
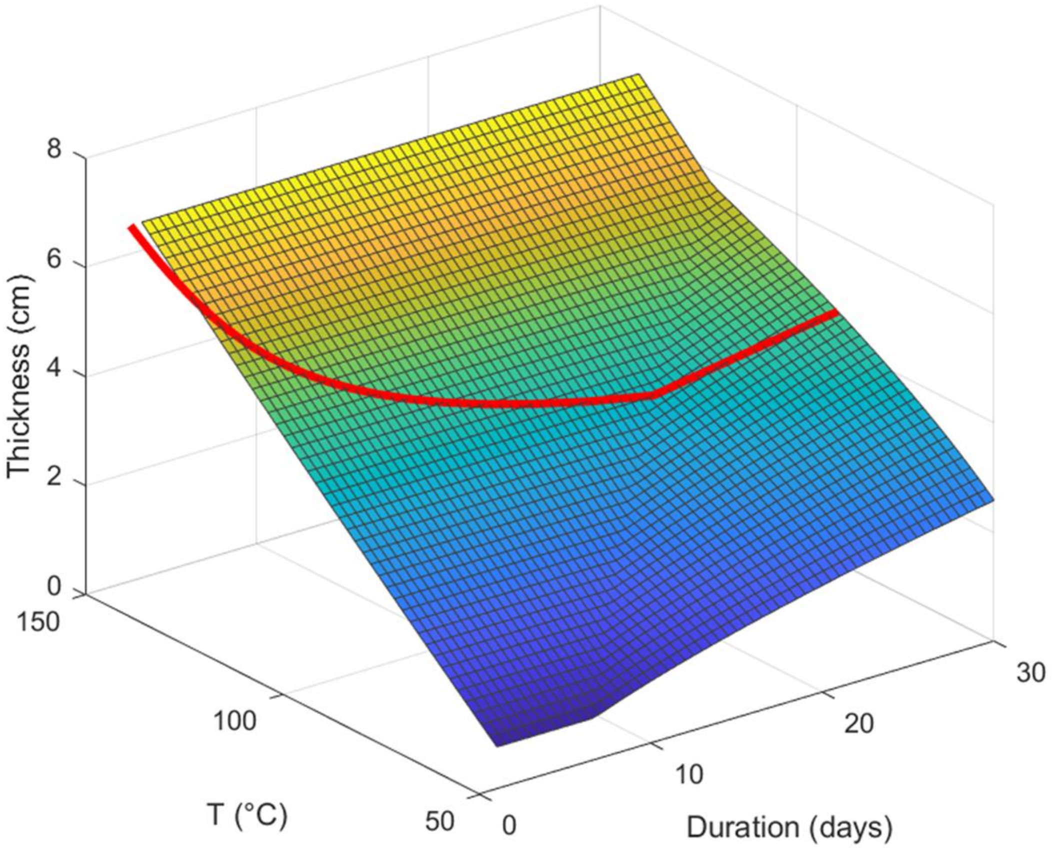


Bakeout duration to reach 2×10^{-11} mbar





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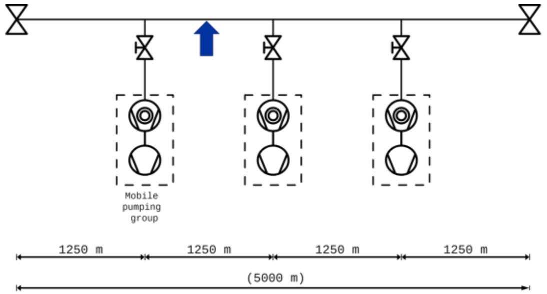

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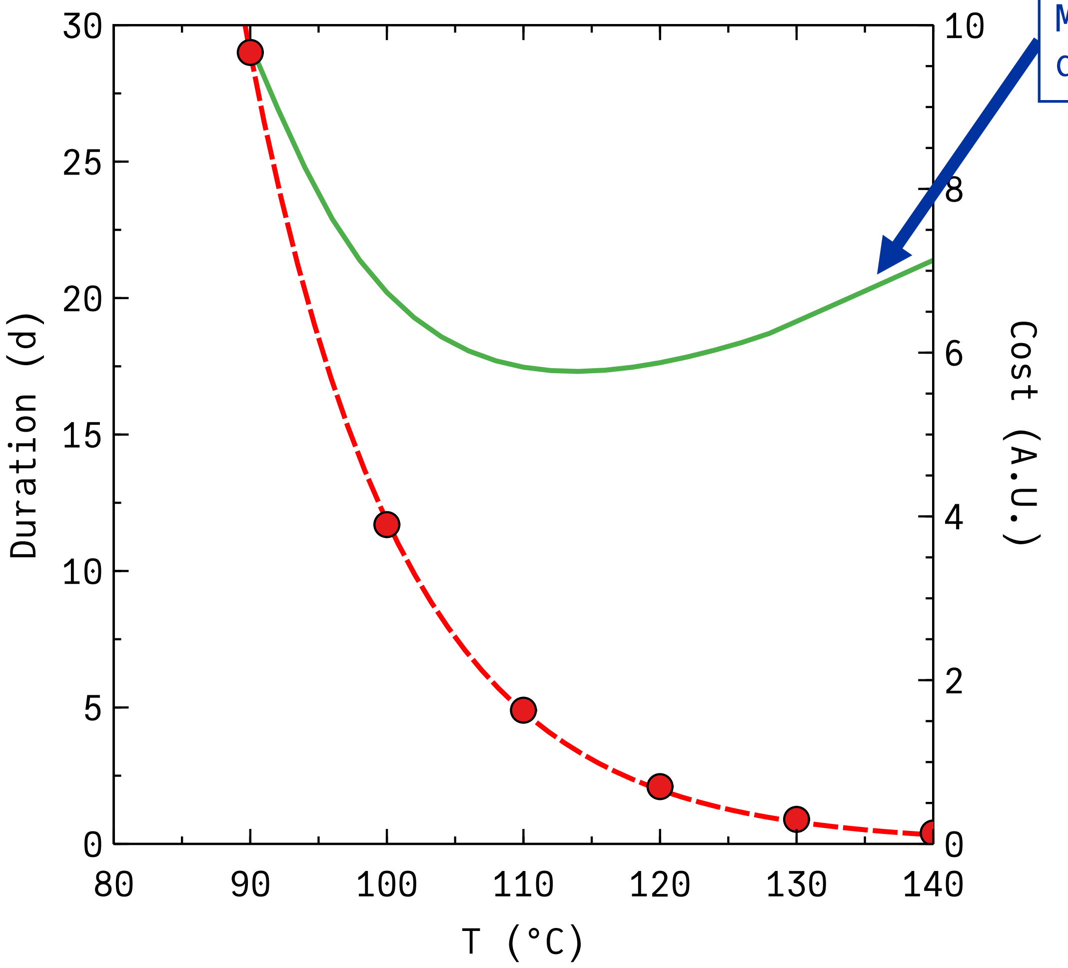
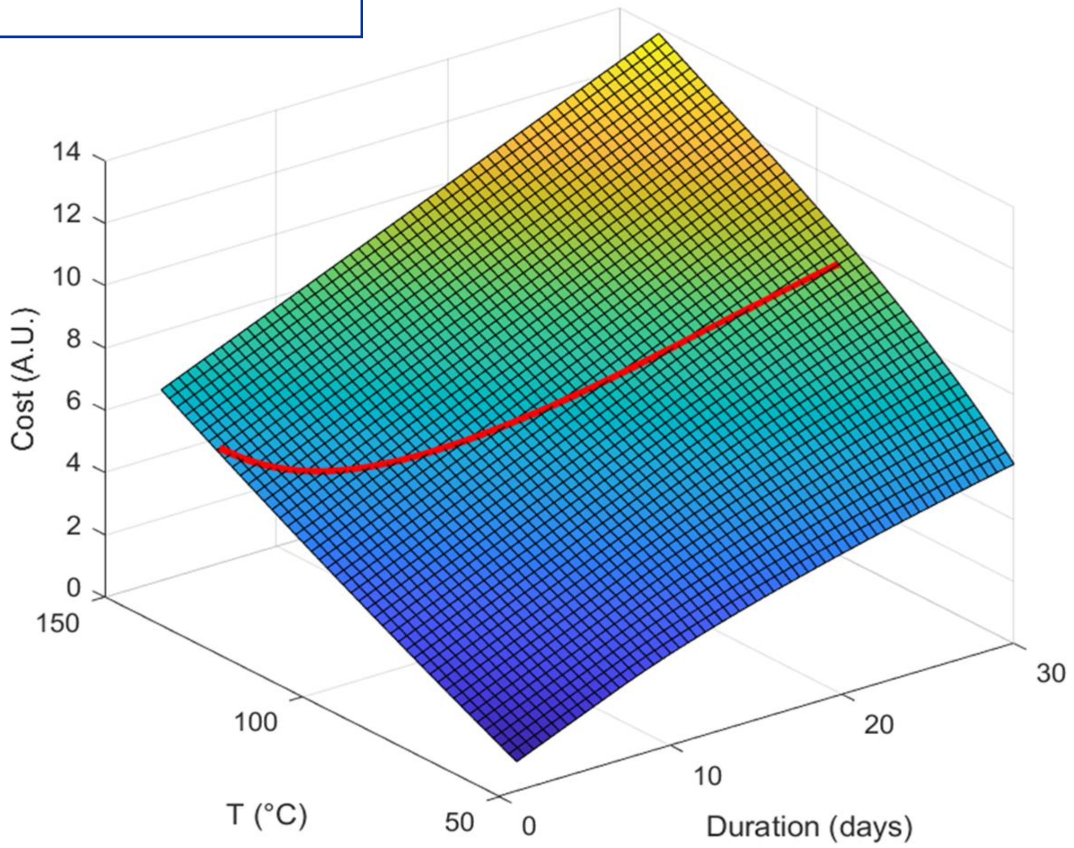


Minimum duration = 1 day



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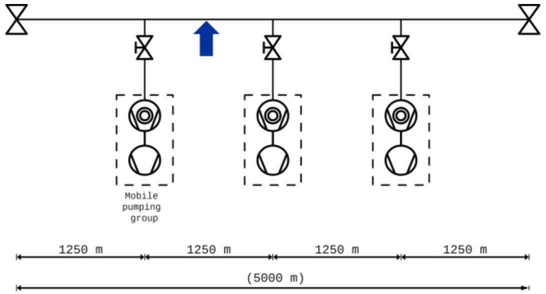

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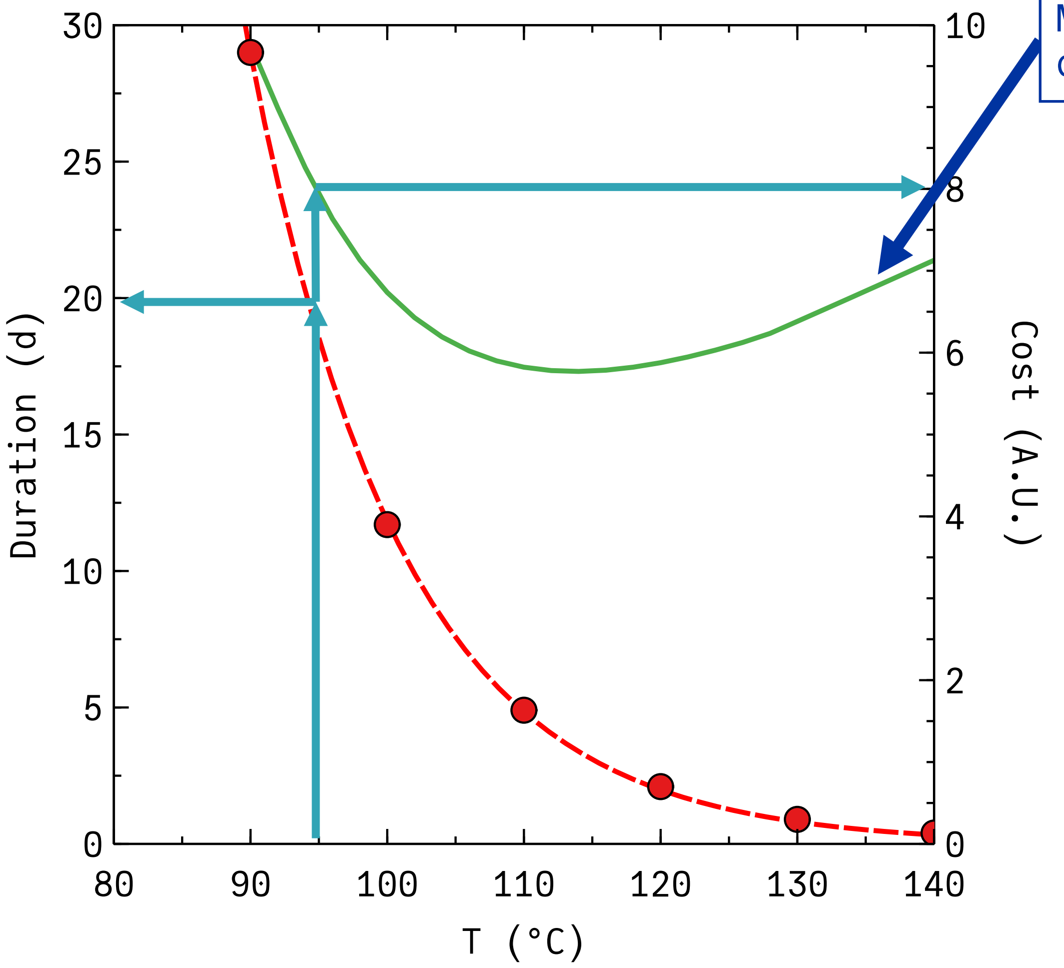

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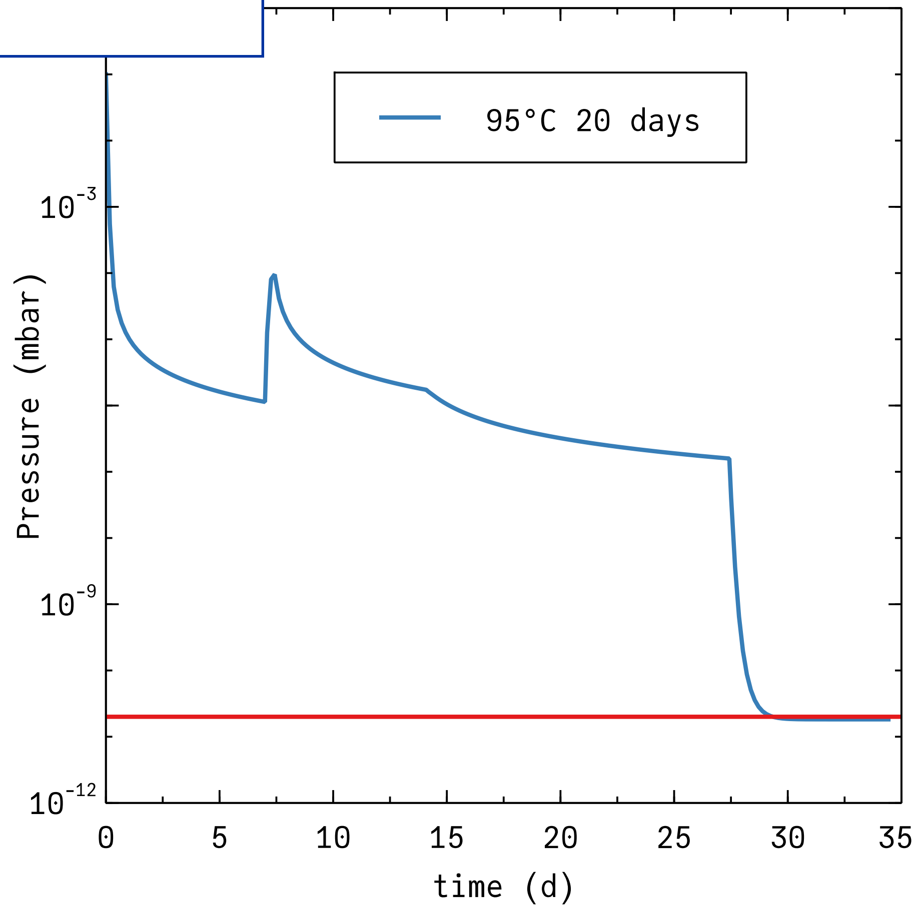

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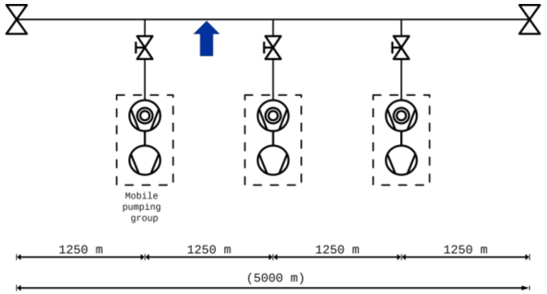

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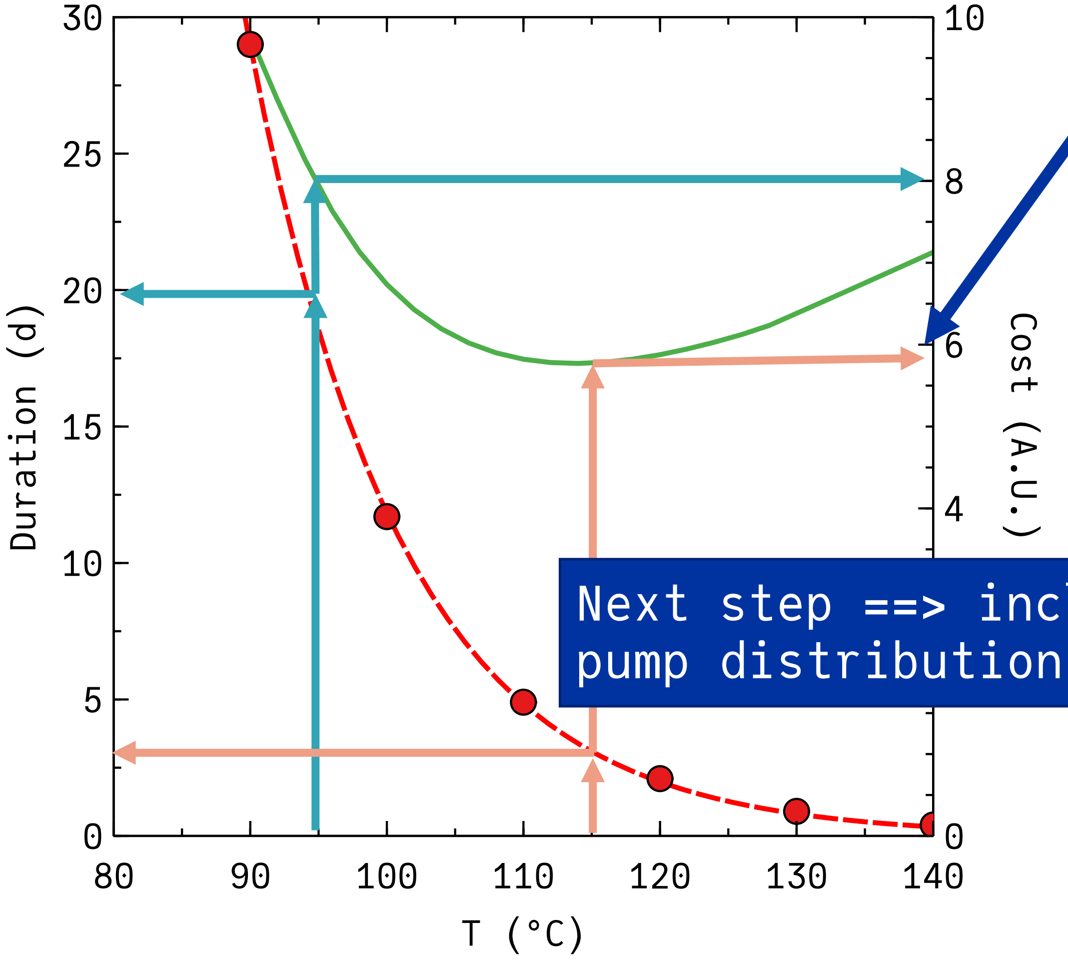
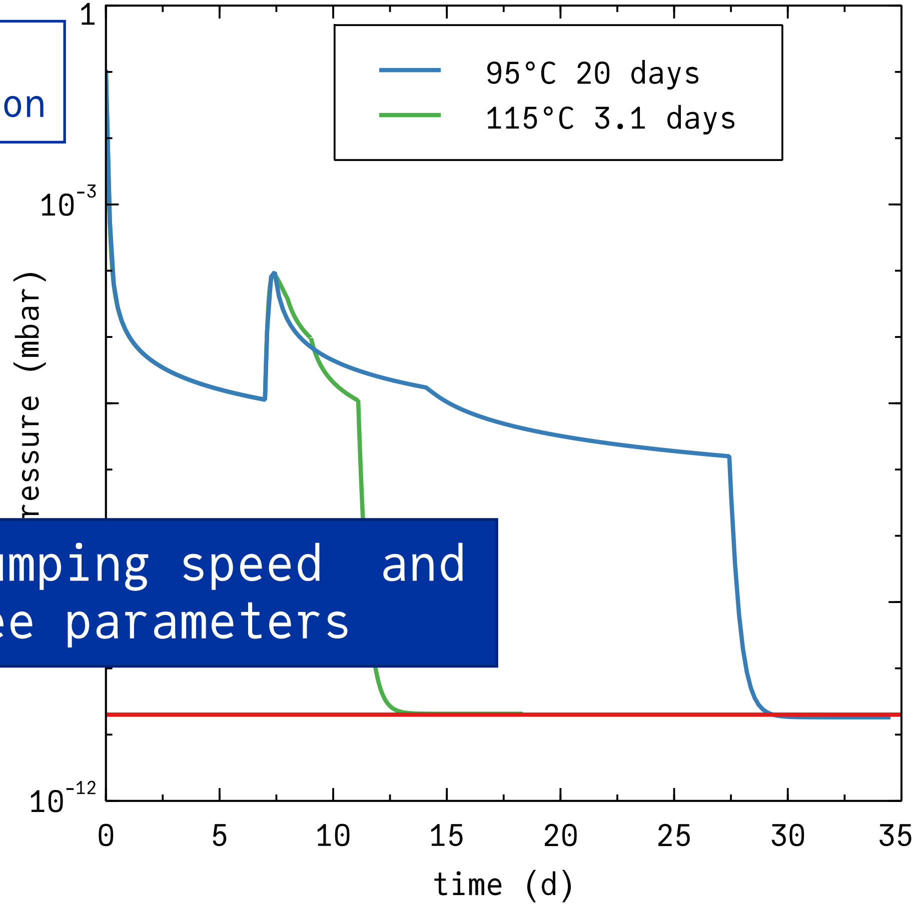


25 % reduction

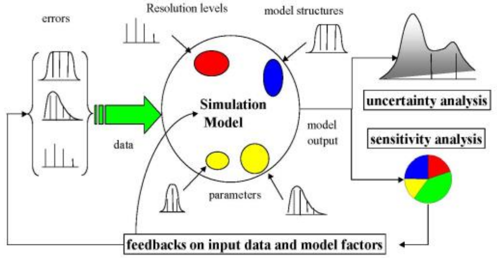


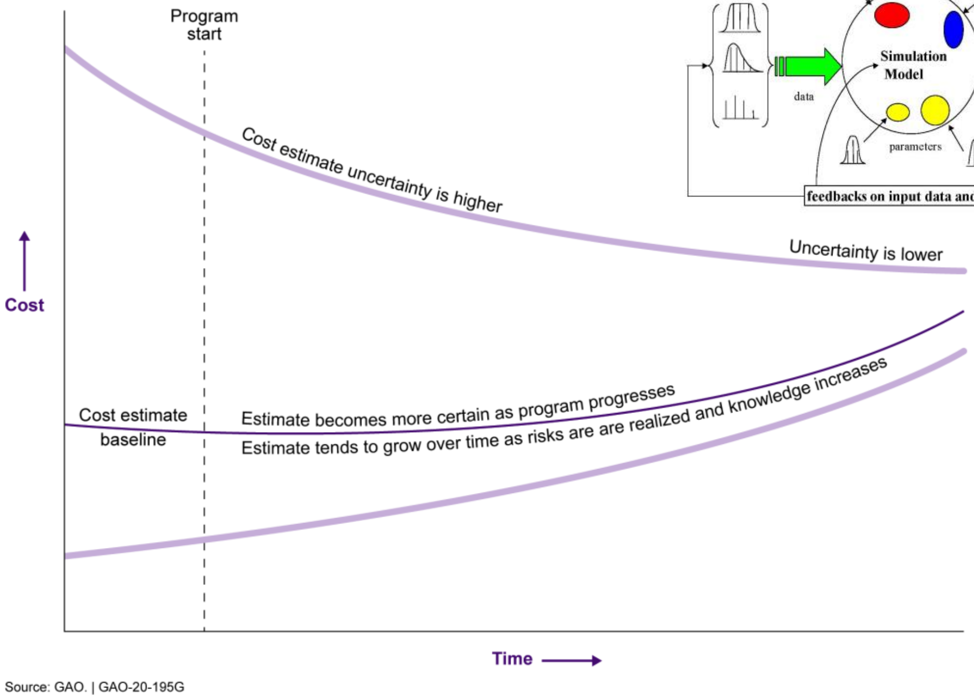
Next step ==> include pumping speed and pump distribution as free parameters

Sensitivity analysis

- The same models used for cost optimization can be used for risk and uncertainty analysis

- Main objectives:
  - Identify main risks
  - Identify variables with high uncertainty
  - Quantify the effect of input changes in the final cost
  - Quantify the cost uncertainty
  - Some decisions can be neutral in cost but not their risk





Summary

- In the coming months we will populate the different cost units
- Identification and set priorities according to cost drivers
- Define a methodology for the cost assessment ==> Systematic justification of design decisions ==> Periodic cost evaluations and release updated information
- Cost model of the different cost units. Optimisation of some design decisions.
- Include sensitivity and risk analysis (build budget with error bars)

Thank you!

References

[1] ET design report update 2020 (ET-0007B-20) https://apps.et-gw.eu/tds/ql/?c=15418

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