# Accelerating and Optimization of foam production using fast and accurate digital prediction tools

Dr. Dariusz Niedziela, Dr. Konrad Steiner

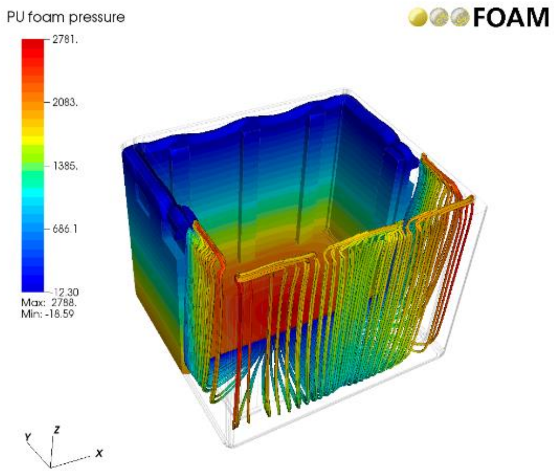
Fraunhofer ITWM
Flow- and Materialsimulation

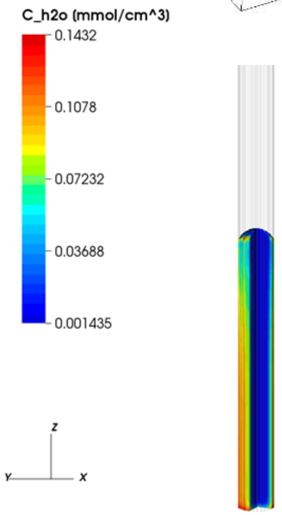
Fraunhofer ITWM

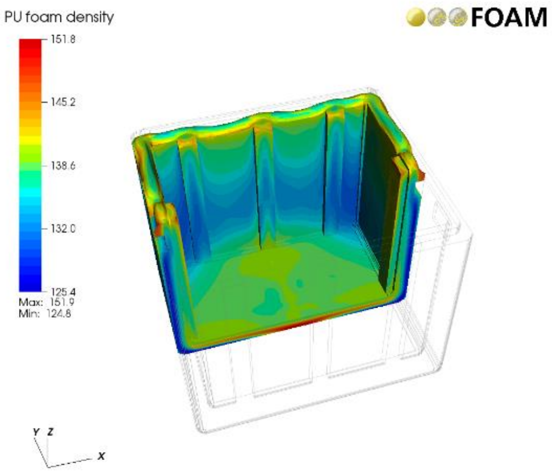
# Process simulation tool

## Simulation of Reaction Injection Molding Processes

- Foaming simulation of various foams (PU, soft foam, rigid foam)
- Simulation based design of foam moulds (placement or path of injection nozzles, position of venting, inclination angle)
- Process design of foaming processes for acoustic or thermal insulation components, sandwich panels, seats, battery packs, cooling units, ..
- Process design of textile-reinforced PU foam lightweight structures
- Output quantities, that are predicted in PUR foam simulations:
  - Flow pressure and velocity
  - Distribution of temperature
  - Degree of polymerization
  - Gas volume fraction, foam density
  - Local mean pore size distribution
  - PUR foam fraction and propagation of foam front



# Agenda:

What is actual possible with FOAM process simulation?
Refrigerator housing

How easy is it to simulate realistic foam processes?
Automated material parameter identification

Accelerating of foam simulation to resolve small details?
Battery packs

# What is actual possible with  FOAM process simulation?
# Refrigerator housing

# Process simulation tool

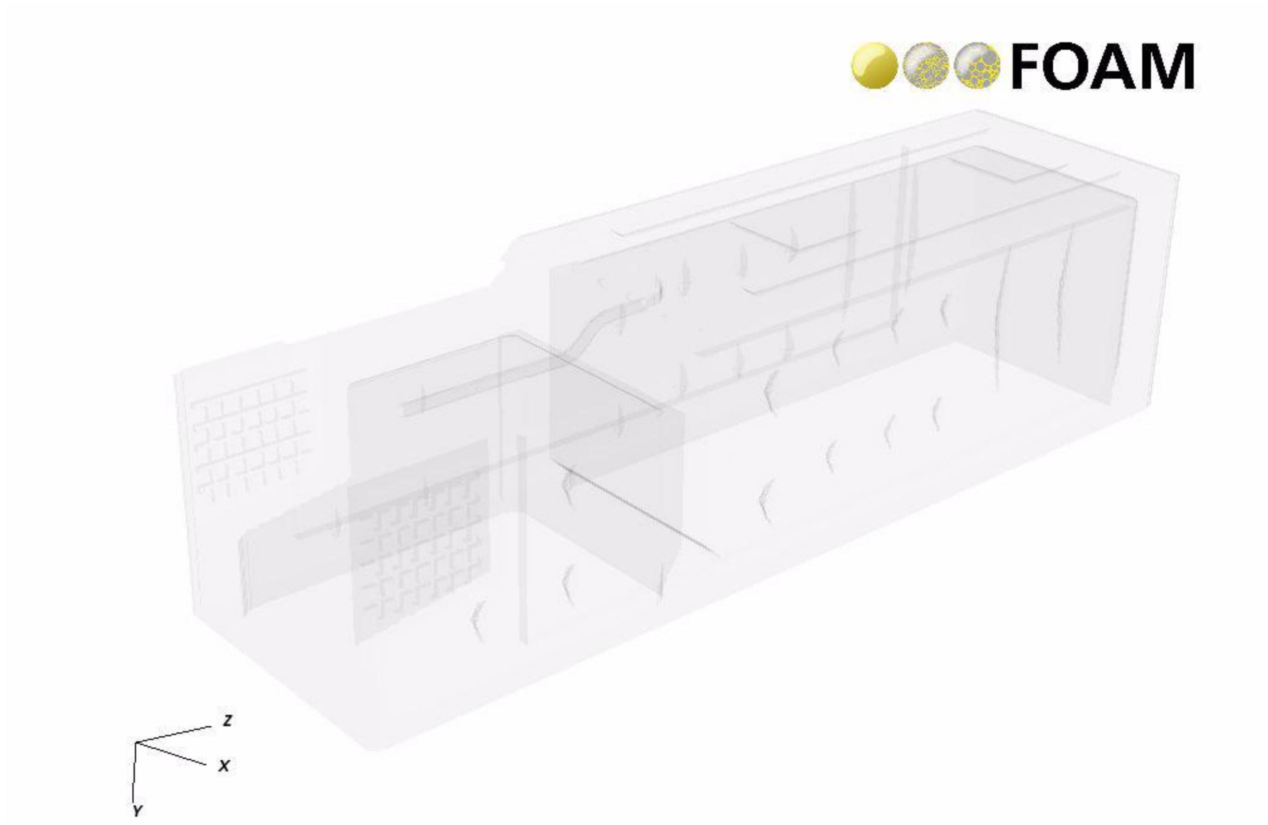
## Example Refrigerator housing

The foaming of refrigerator parts is a demanding process that requires optimization steps regarding various factors:

- injected mass, injection position, number of injection points,
- venting positions, foam characteristics

Starting conditions

- Injection: 3.5kg material over 5 (s) per injection position
- Wall temperature: 45°C
- Injected material temperature: 28 °C
- Foam density 1208 kg/m³
- Initial pressure 1 bar
- Cream time 2 s



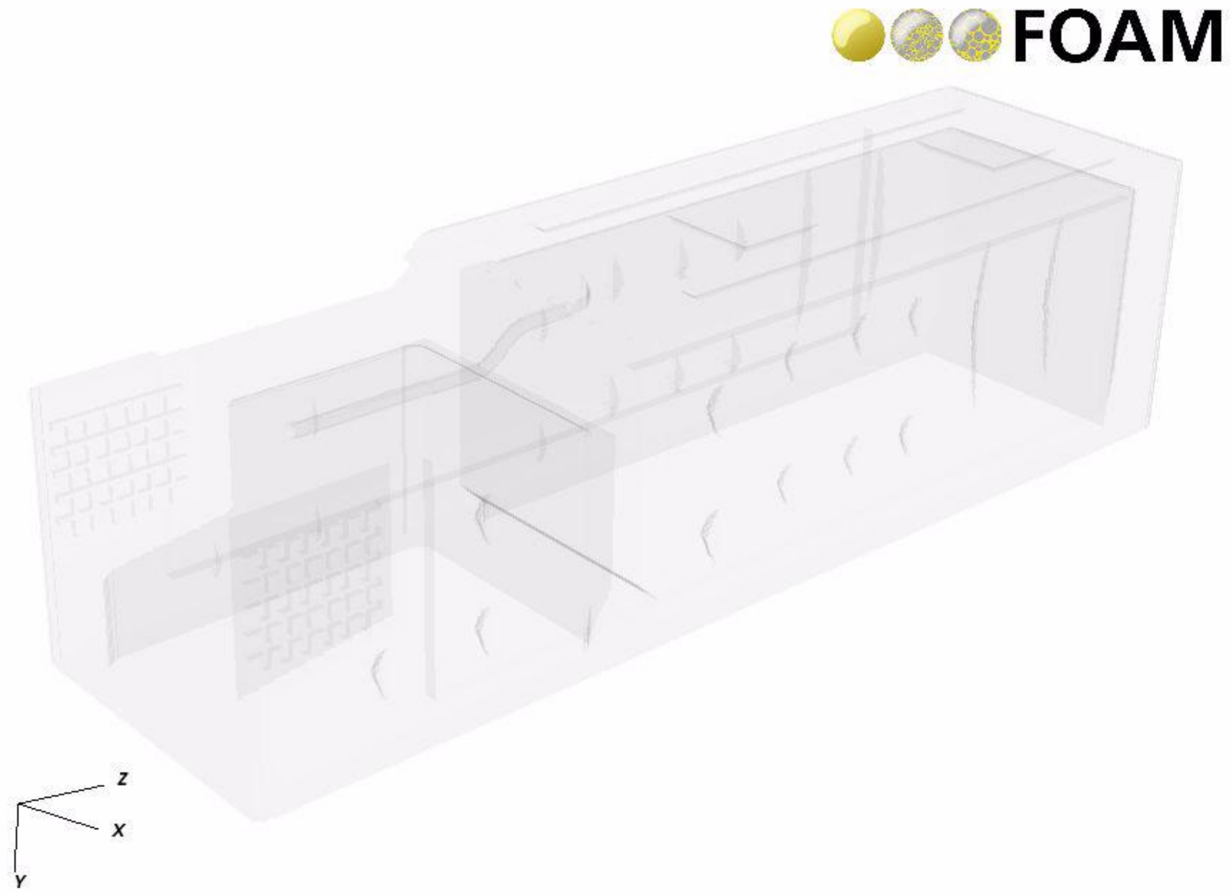
Fraunhofer ITWM

# Process simulation tool
## Example Refrigerator housing

- Process setup correction:
  - Injection position moved
  - Additional vents in the top-middle sectio
  added

Same starting conditions

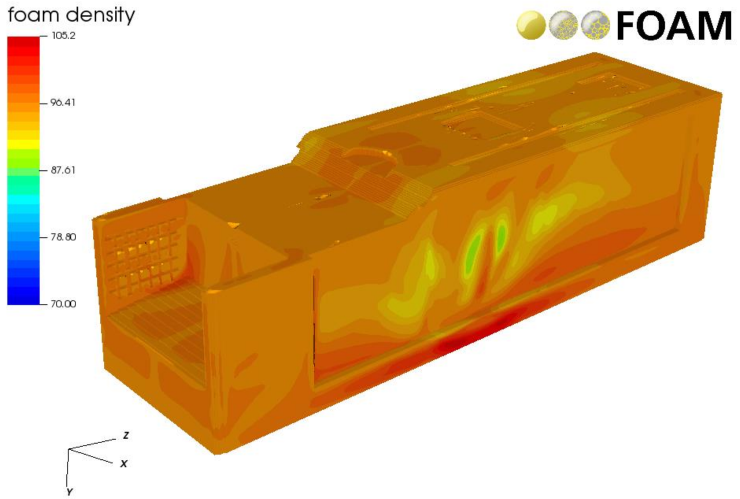
- Injection: 3.5kg material over 5 (s) per
  injection position is injected.
- Wall temperature: 45°C
- Injected material temperature: 28 °C
- Foam density 1208 kg/m³
- Initial pressure 1 bar
- Cream time 2 s

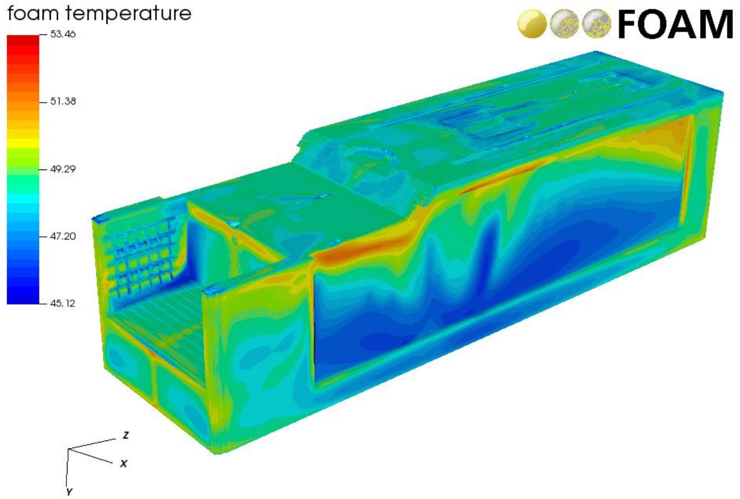


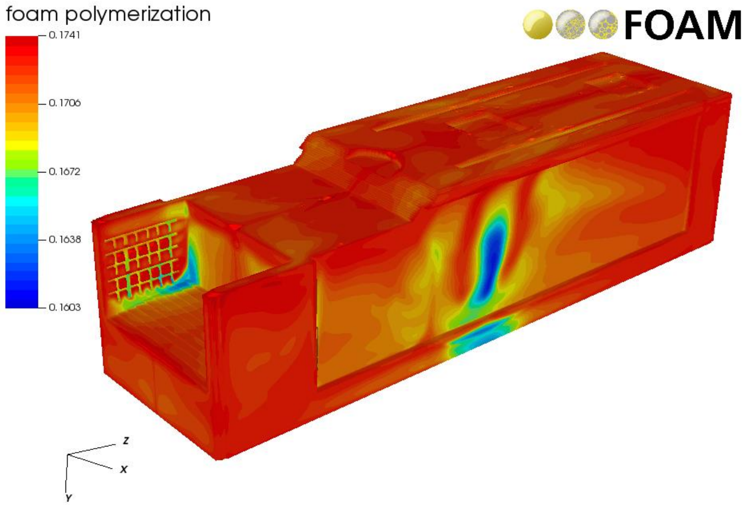
# Process simulation tool
## Example Refrigerator housing

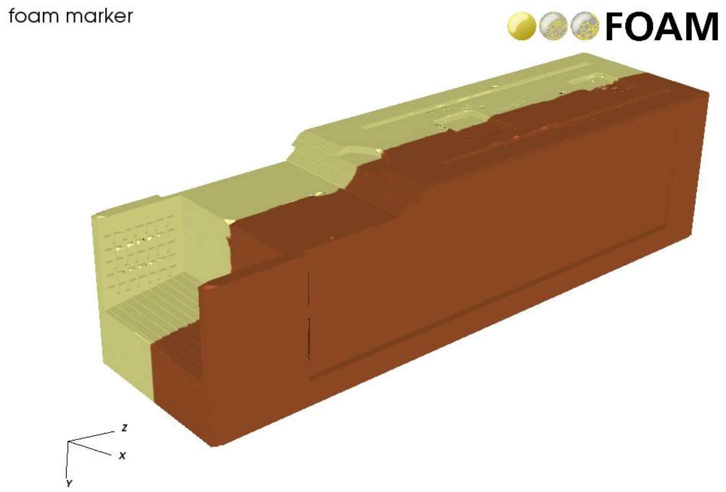
- Foam expansion simulation delivers:
  - foam density
  - foam temperature
  - gas voids
  - foam polymerization
  - foam type markers







Fraunhofer ITWM

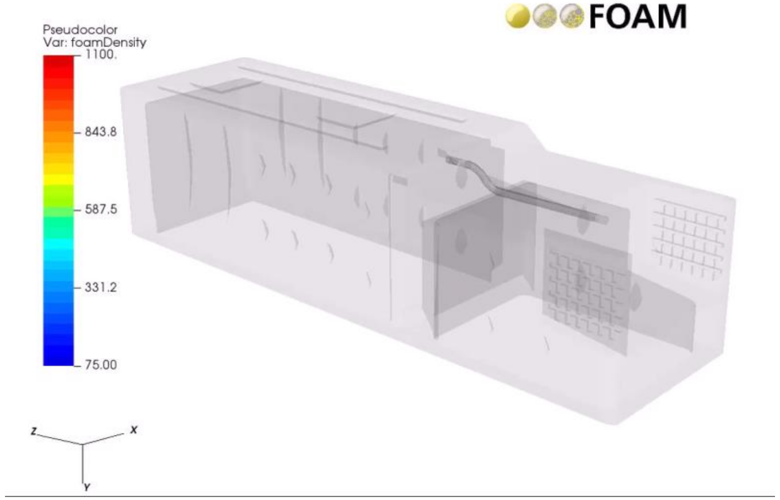
# How easy is it to simulate realistic foam processes?
# Automated material parameter identification

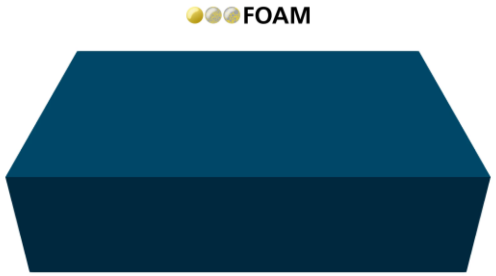
 

FOAM

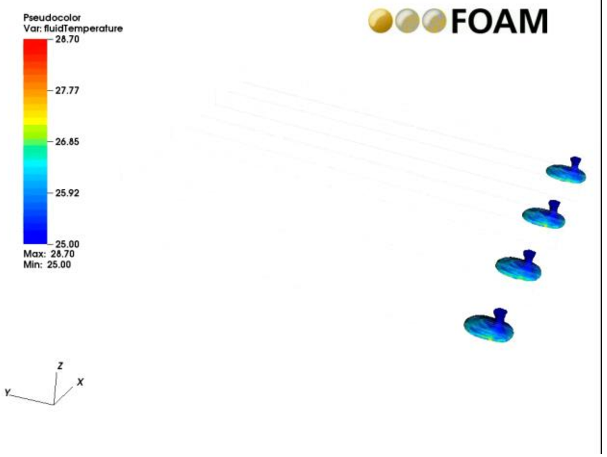
# PU foam material description for foam expansion

- Production of PU foams involves chemical reaction between polyols, isocyanate and blowing agents;
- Primary reaction occurs between polyols and isocyanate that creates polyurethane;
- Chemical blowing agents, like water, form a secondary reaction with isocyanate. As result amines and carbon dioxide ($CO_2$) are produced;
- Curing process, generated heat.
- 2 phase system is solved, foam and surrounding gas.







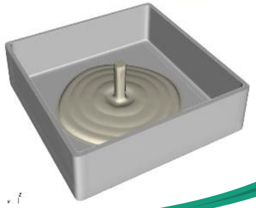
# Rheology of PUR foam

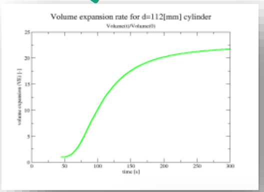
## Automated tool for model input parameters identification

$$\nabla \cdot \mathrm{v} = \mathrm{S_p}(\mathrm{t},\mathrm{T},..)$$

$$\frac{\partial \rho \mathrm{v}}{\partial \mathrm{t}} + \nabla \cdot (\rho \mathrm{v}\mathrm{v}) = \cdots .$$

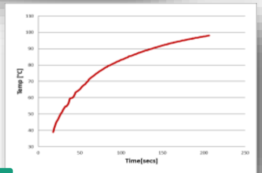
$$\mu = \mu_0 e^{\left(\frac{E_R}{T}\right)} \ldots .$$

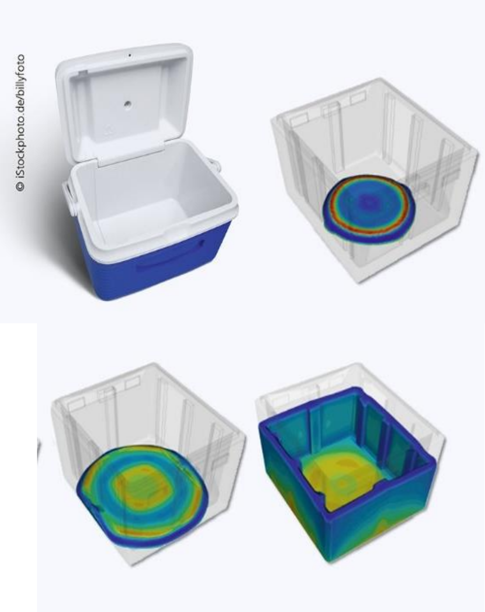





$V(t)$

$\mathrm{T}(t)$






- Minimal experimental data required for setting foam model input:
  - Foam expansion experiments in cylindrical geometries with measurements of temperature (or FOAMAT measurements)
  - Foam expansion in rectangular box (or measured viscosity data).

- All parameters are highly coupled with all quantities
- **Automated input parameters identification from simple experiments**

# Accelerating of foam simulation to resolve small details?

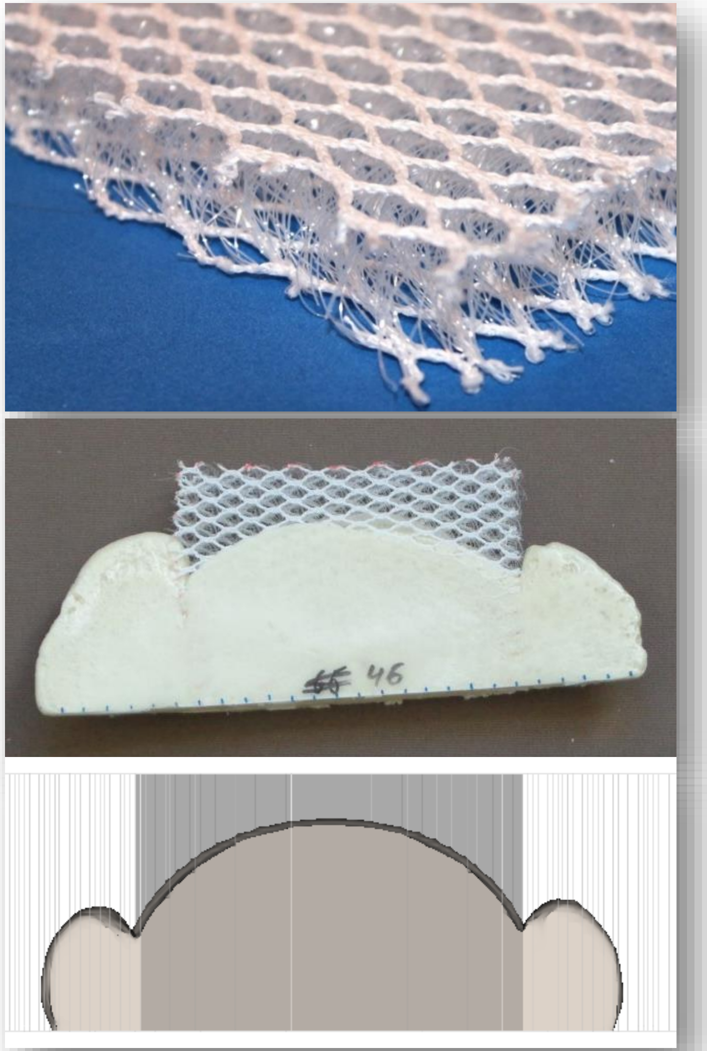
# Battery packs

# Foaming simulations of tiny part

## Challenges and speedup option

- FOAM simulations deliver reliable results in reasonable time, however …
- Often, cavities posses very fine or highly packed parts like:
  - cables
  - mesh structures
  - packed cells, etc.
- Existence of such elements produce narrow regions that foam could fill.
- On one side such parts are very important places of interest, as are hard to fill.
- On the other side are very challenging for simulation as proper meshing leads to high number of grid elements.
- High number of grid elements together with large process time results in large simulation times (even weeks)

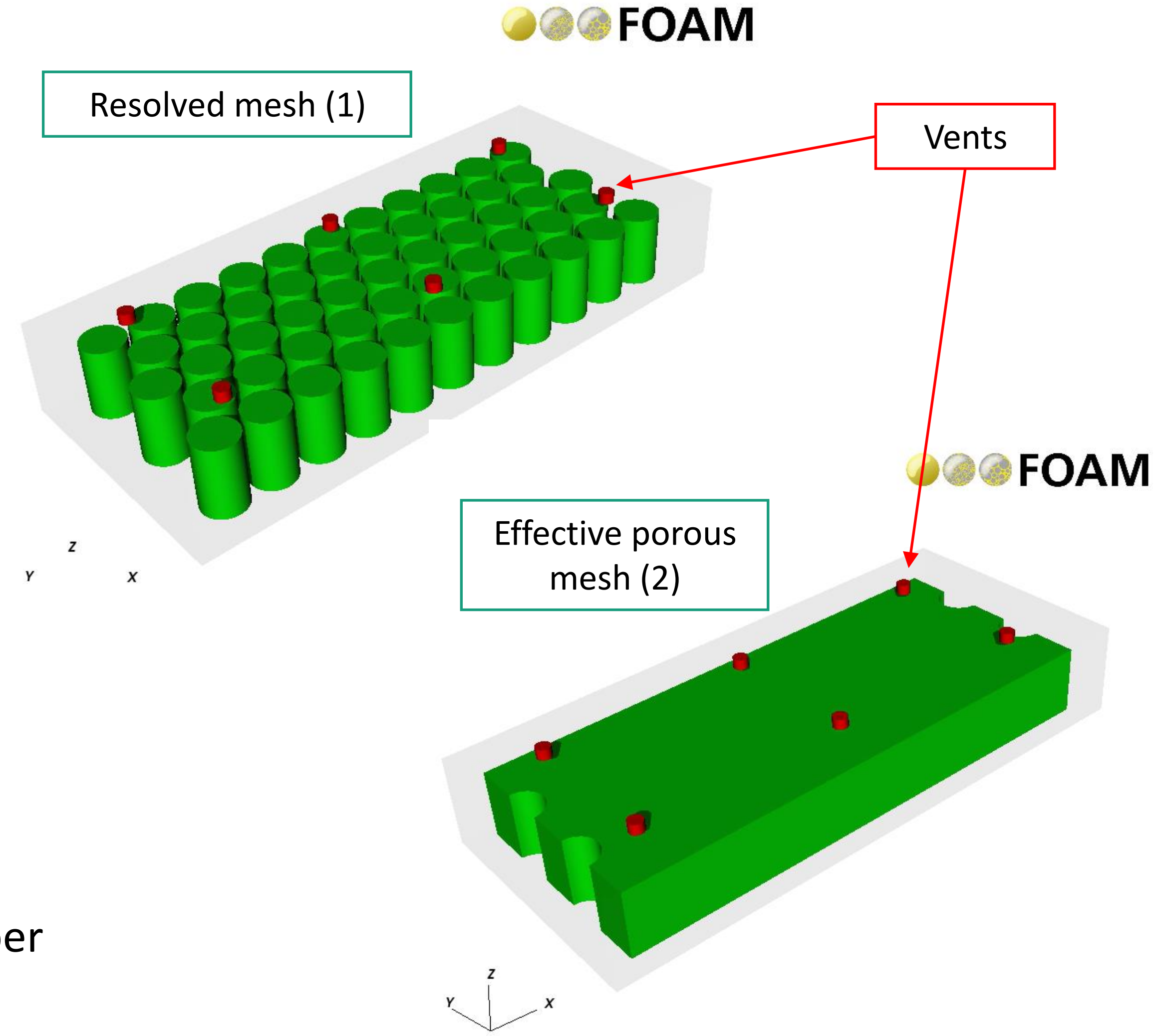
→ Not suitable for industrial design purposes.



# Foaming simulations of battery pack

## Process definition and geometry setup

- We consider battery consist of 53 cylindrical cells.
- Injected material: 3.5 (kg) over 20 (s)
- 2 injection strategies tested:
  - point injection
  - path injection
- Injection nozzle: 15 (mm)
- Cavity temperature: 24 °C
- Injected foam temperature: 23 °C
- Foam density (not expanded): 1220 (kg/m³)
- Two simulation geometries considered:
  - fully resolved cylinders (1) : number of mesh elements: 2.338 Mio
  - cylinders treated with effective porous region (2): number of mesh elements: 0.433 Mio



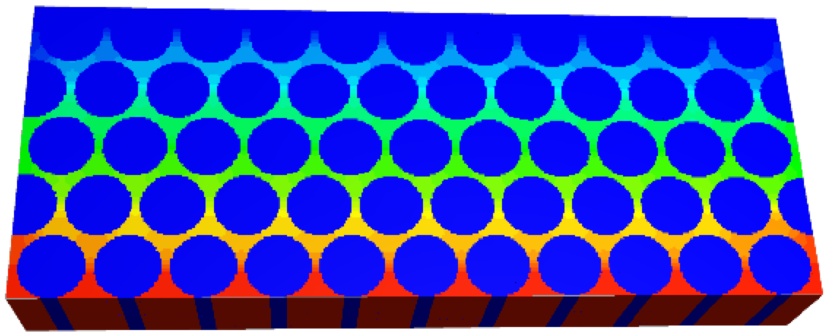
# Foaming simulations of battery pack.

## Effective porous part modeling.

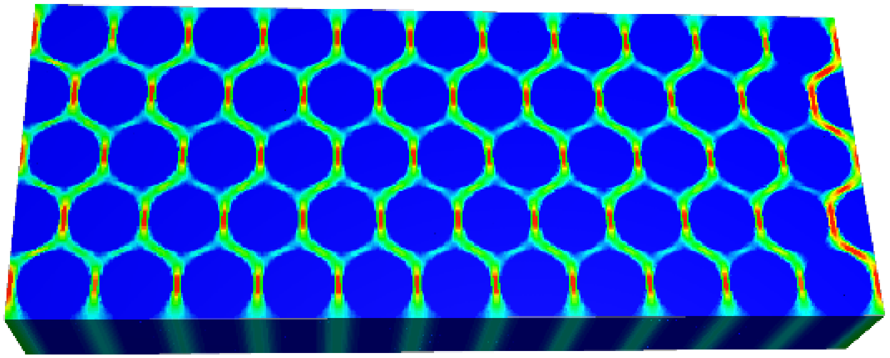
- For porous part we require information of:
  - permeability
  - porosity
- Both values have been calculated.
- Porosity: 30%
- Permeability

Permeability:

$$K = 10^{-7} \begin{bmatrix} 4.636 & 0 & 0 \\ 0 & 4.636 & 0 \\ 0 & 0 & 23.07 \end{bmatrix} (m^2)$$



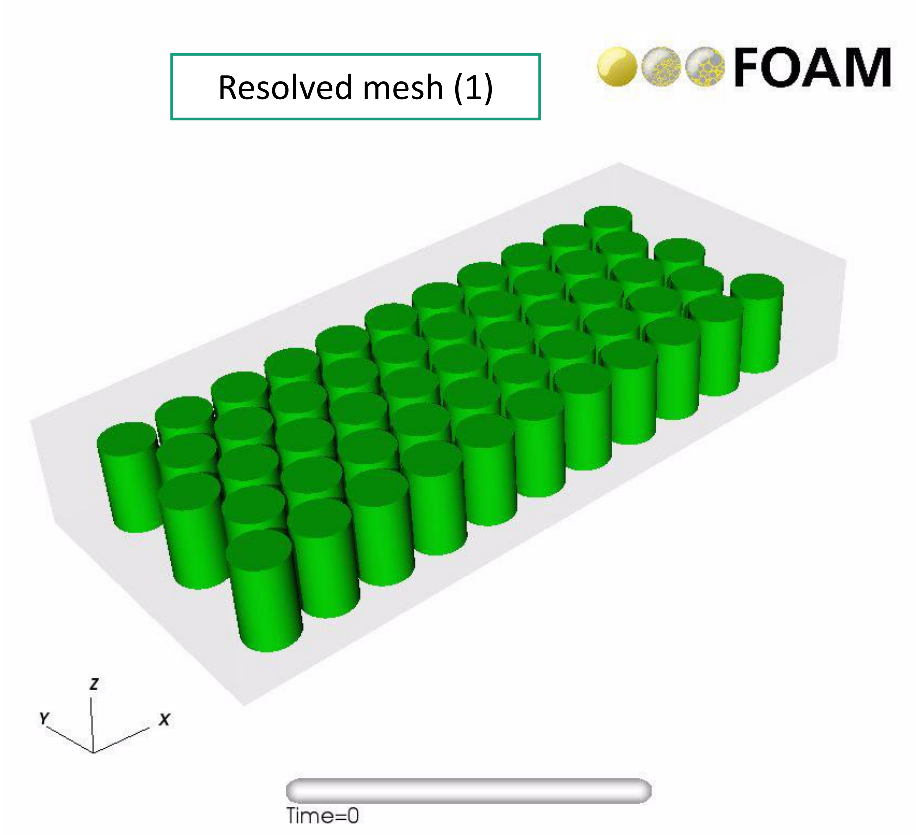
Permeability tensor calculated based on one-phase Stokes equation

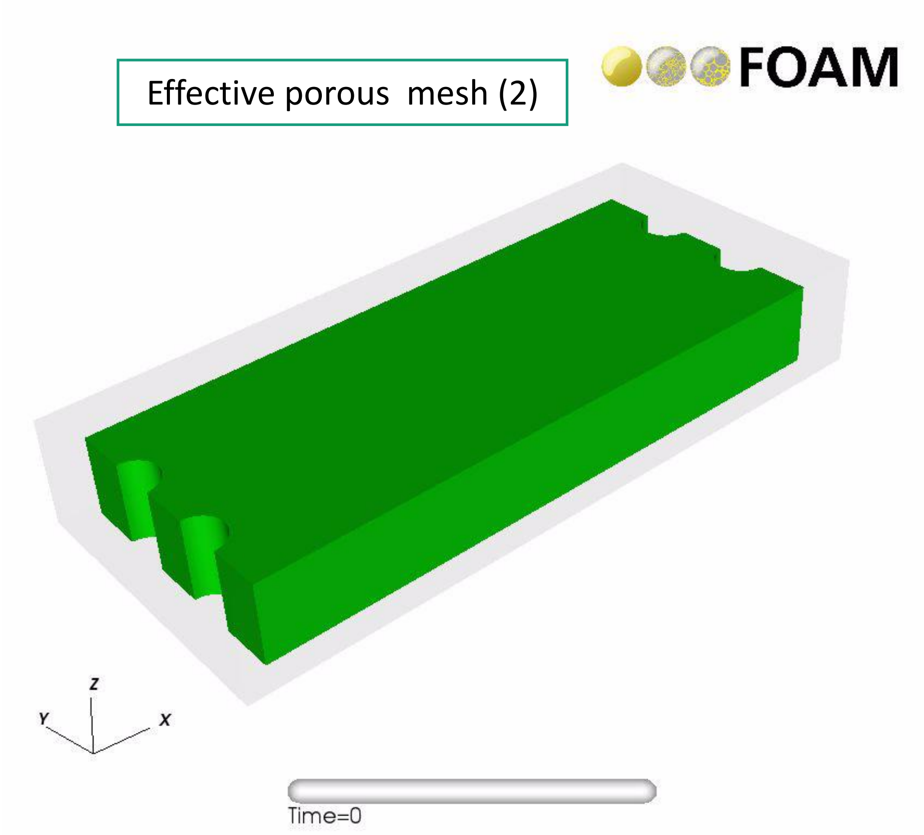


# Foaming simulations of battery pack.

## Battery cells – point injection example



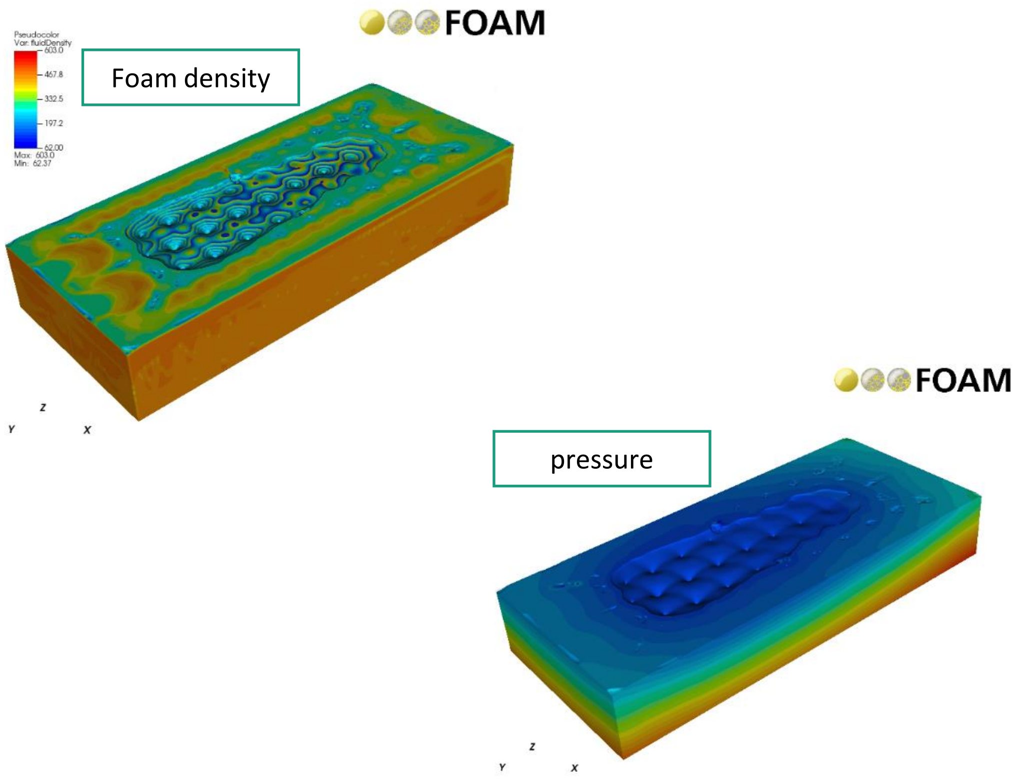




 05.12.2024 

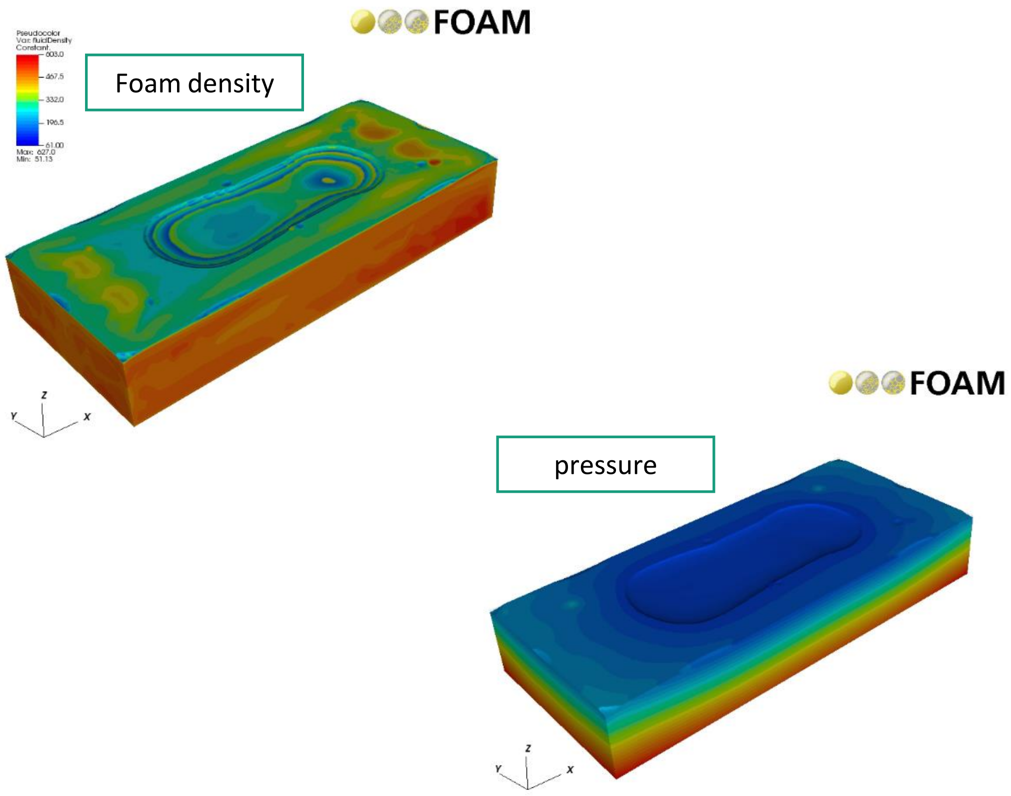
# Foaming simulations of battery pack.

## Battery cells – point injection example.

Resolved mesh (1)




Effective porous mesh (2)

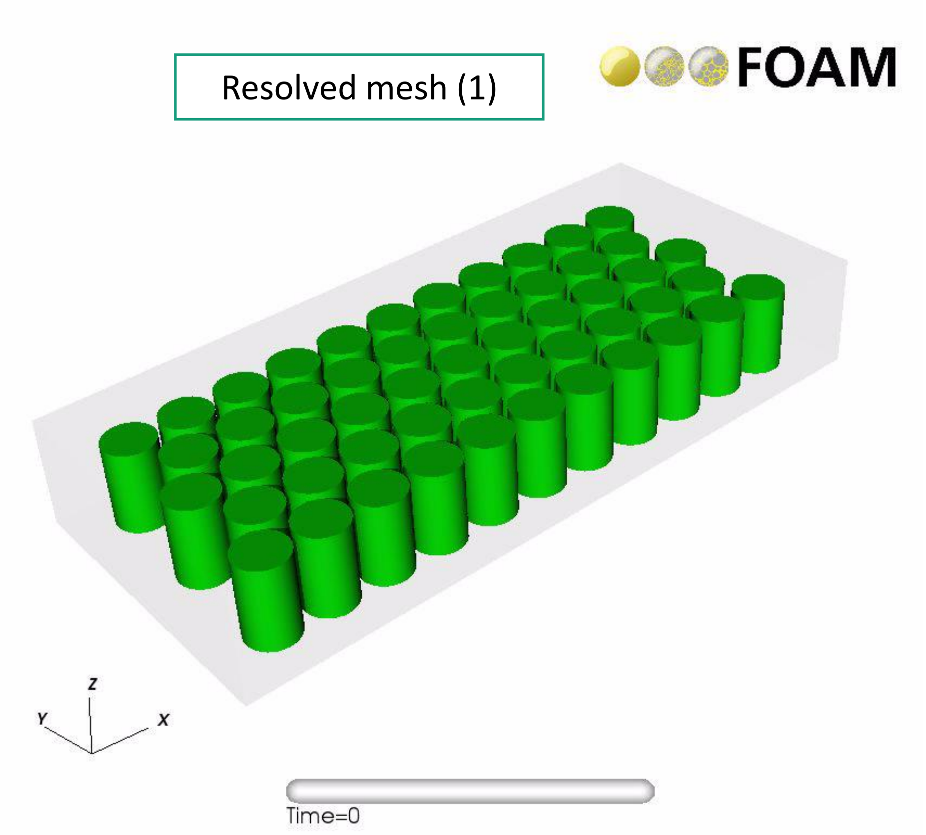


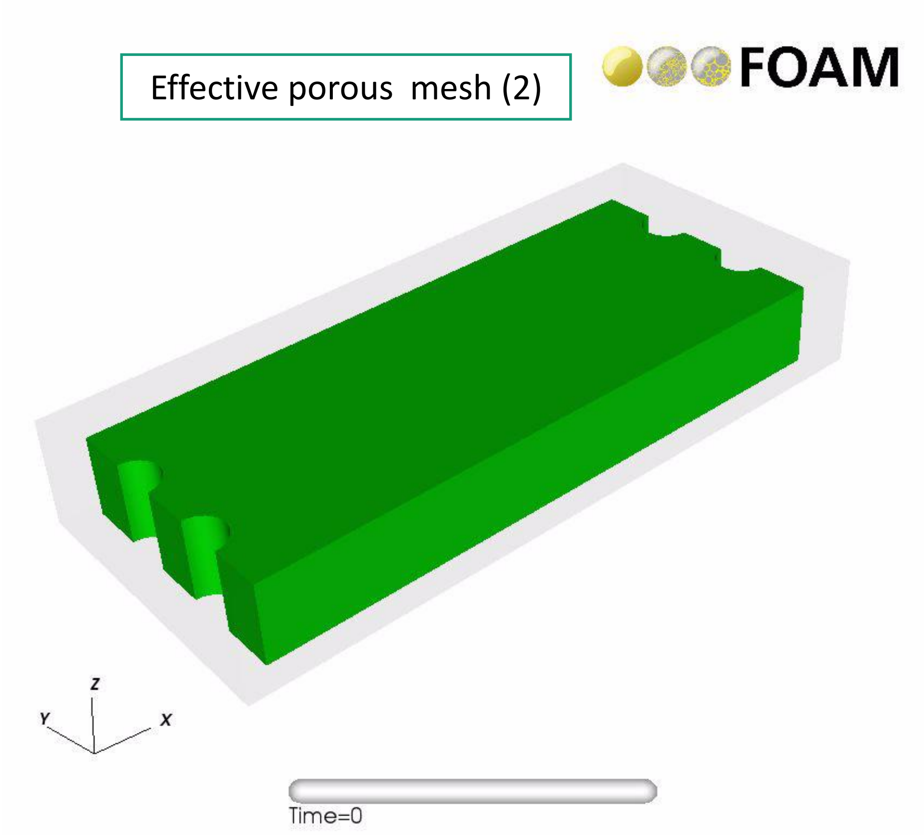

 

Fraunhofer ITWM

# Foaming simulations of battery pack

## Battery cells – path injection example



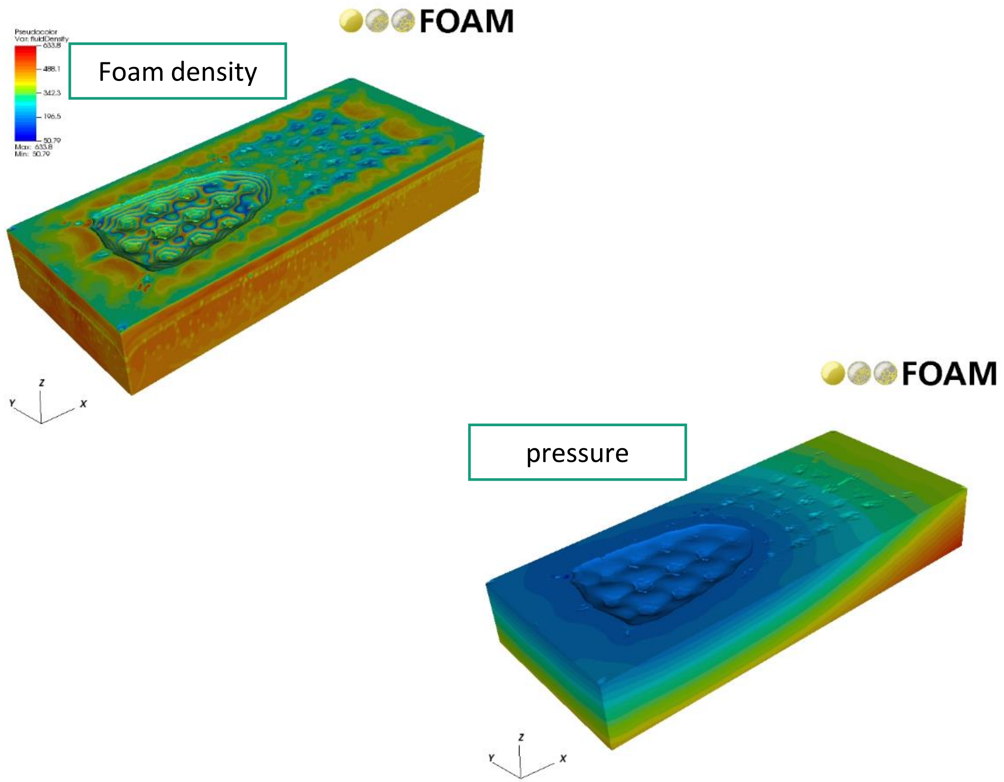



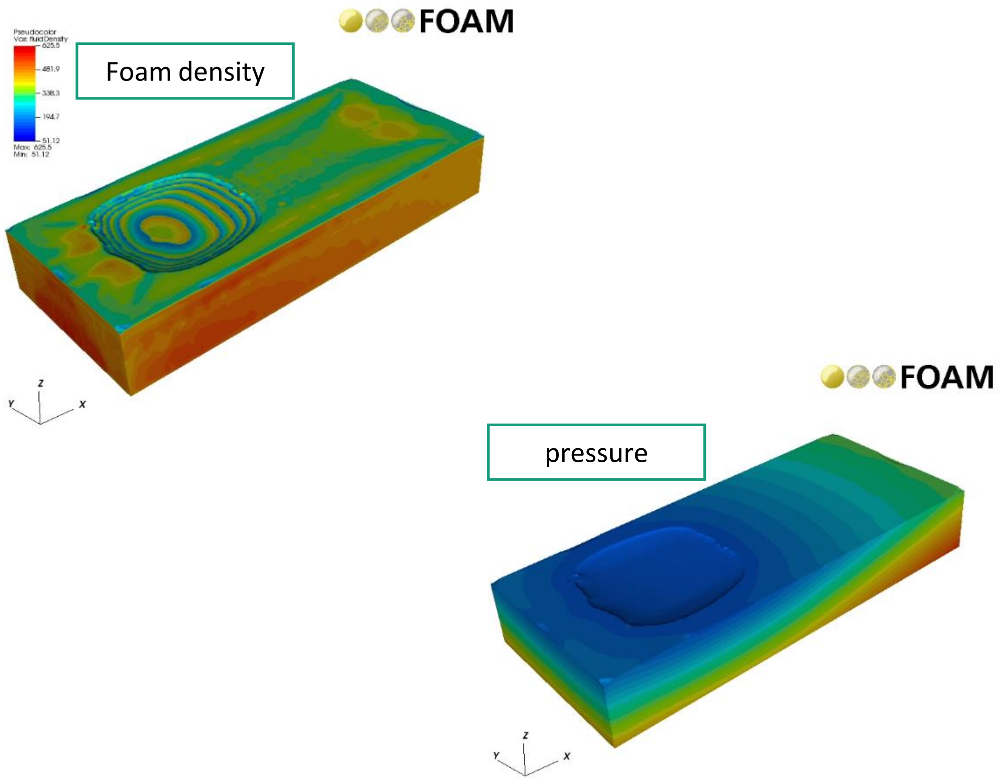
# Foaming simulations of battery pack

## Battery cells – path injection example

Resolved mesh (1)




Effective porous mesh (2)



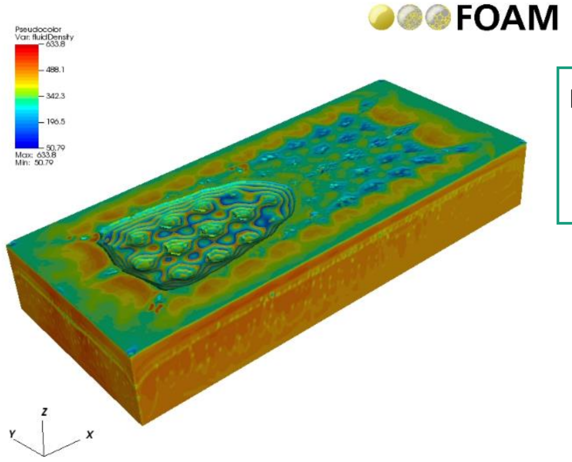
# Summary:  Porous Foam simulations

- Benefits from method:
  - Large simulation run time speedup: for presented cases we achieved results  around 12 times faster.
  - Very good agreement in foam density, pressure, fill time, gas voids, etc.
  - Allows to simulate larger cavities in reasonable time.
  - Allows to consider very narrow parts that usually are omitted due to simulation time constriction.

**Computational Speedup: > 10 times**

**Memory reduction: > 5 times less**

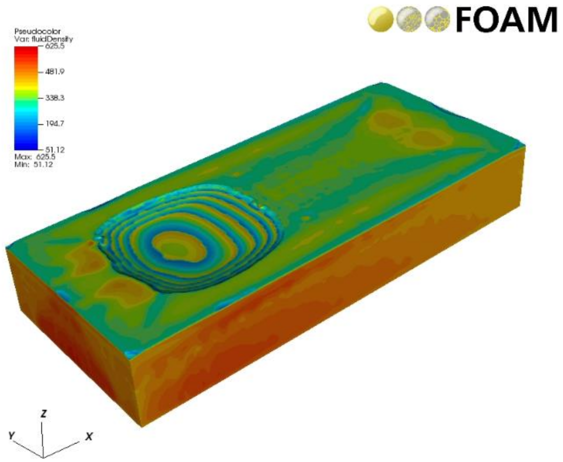
**Small tiny structures can be considered with reasonable effort**




Mesh size: 2.338 Mio elements

Simulation time: 36h 35m

Process time: 82 s




Mesh size: 0.446 Mio elements

Simulation time: 2h 56m

Process time: 82 s

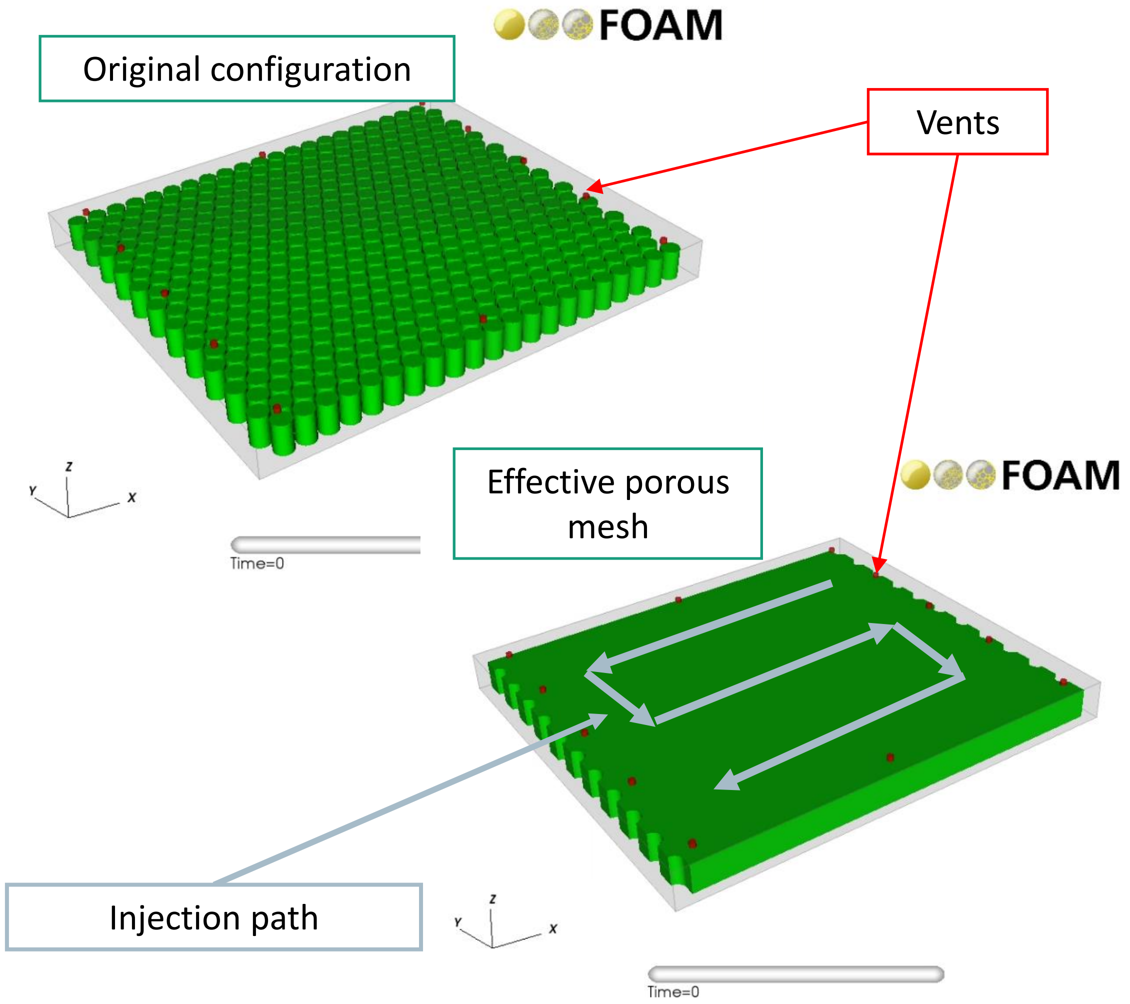
Fraunhofer ITWM

# Foaming simulations of battery pack

## Large scale example - process definition and geometry setup

**Large problems can only be calculated with reasonable effort**

- We consider battery consist of 462 cylindrical cells.
- Cylinders treated with effective porous region (2): number of mesh elements: 1.34 Mio
- Injected material: 20 (kg) over 30.5 (s)
- Path injection indicated on right plot.
- Injection nozzle: 20 (mm)
- Cavity temperature: 24 °C
- Injected foam temperature: 23 °C
- Foam density (not expanded): 1220 (kg/m³)



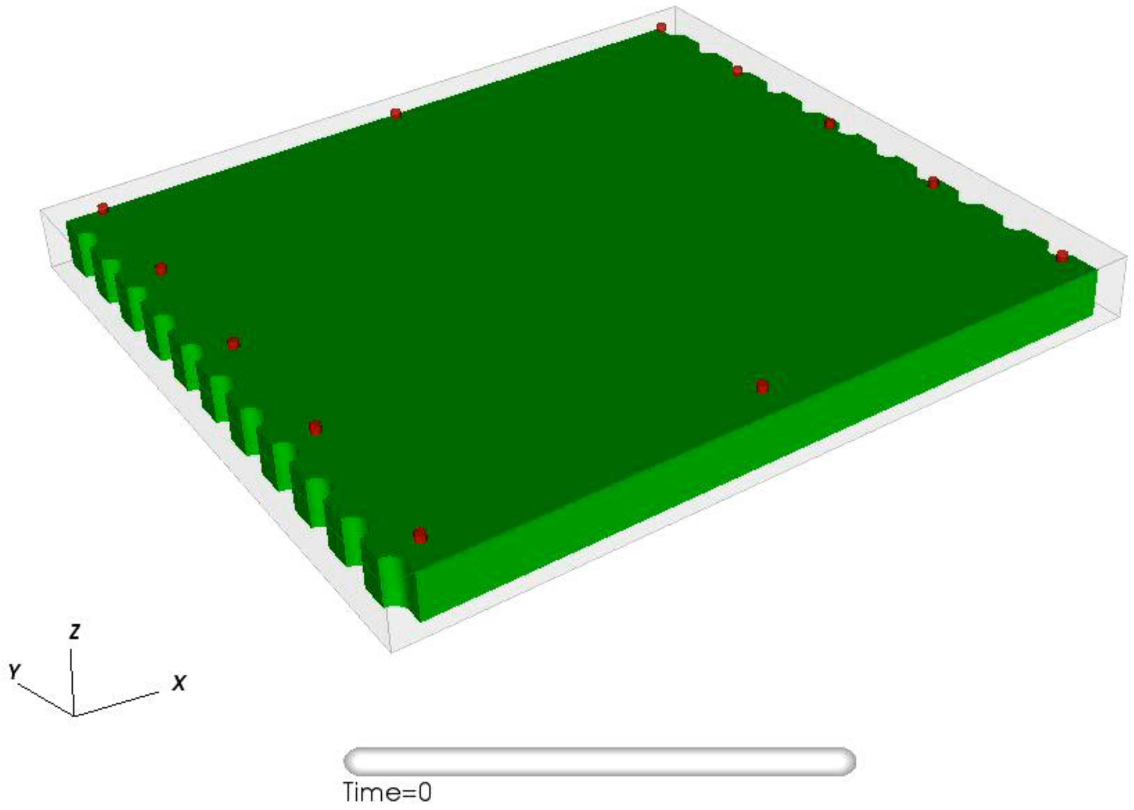

 

Fraunhofer ITWM

# Foaming simulations of battery pack

## Large scale example battery cells simulation

- Simulation results:
  - Large scale simulation performed in reasonable time. Simulation run time: 21h.
  - Full process foaming time: 90 s
  - Clear gas void detected.
  - Optimization: change injection path and/or vent numbers and positions




 05.12.2024 

# Thank you for your attention

Contact: Fraunhofer Booth H1-250

—

Dr. Konrad Steiner
Tel. +49 63131600-43242
Konrad.steiner@itwm.fraunhofer.de

Fraunhofer ITWM
Fraunhofer-Platz 1
67663 Kaiserslautern
www.itwm.fraunhofer.de/sms