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Modeling the Internal Pressure Distribution of a Fuel Cell

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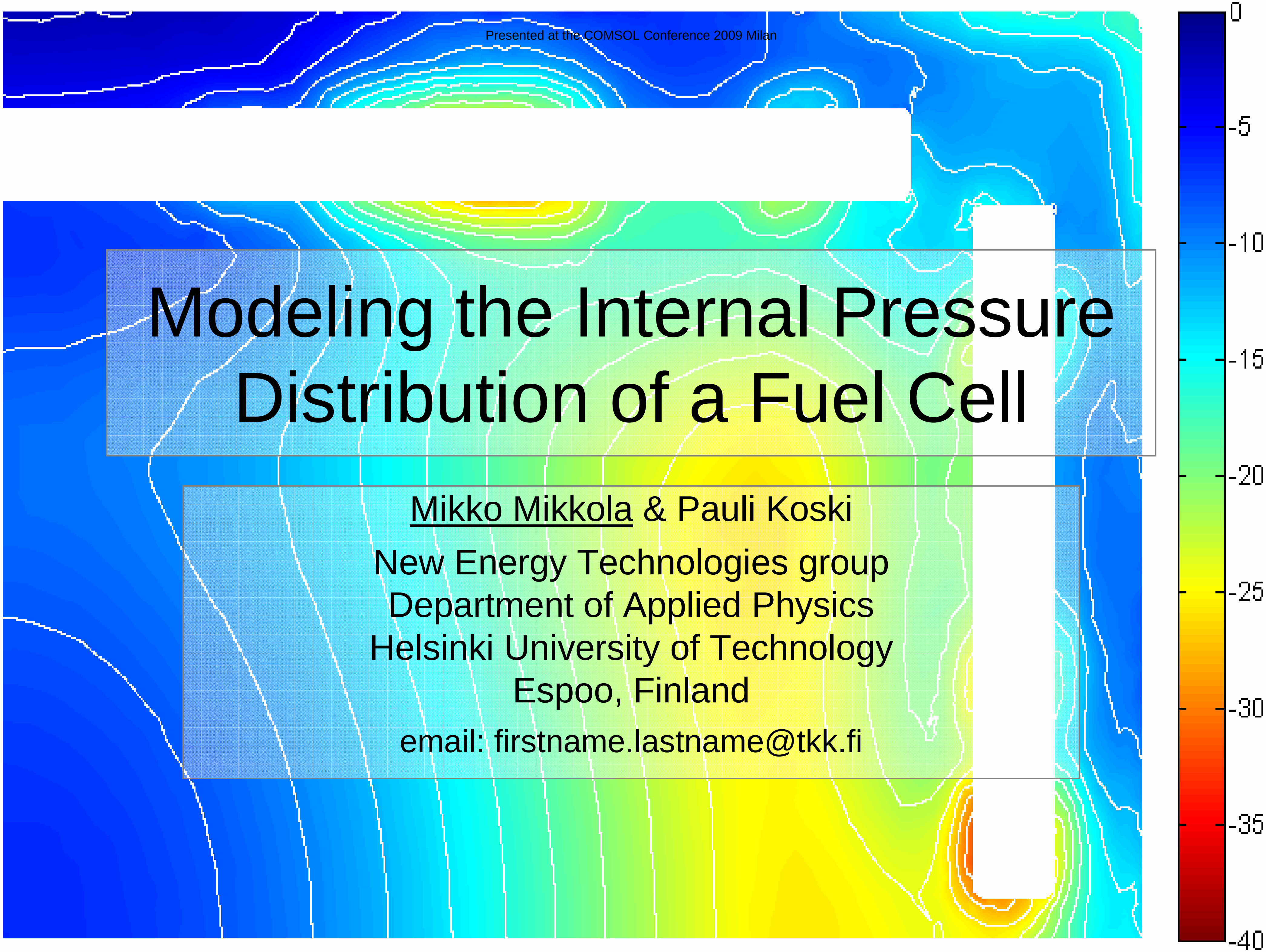

What are fuel cells?

- Electrochemical devices that convert the chemical energy of reactants directly into electricity and heat
- Oxidation and reduction physically separated and charge carriers forced to take separate paths

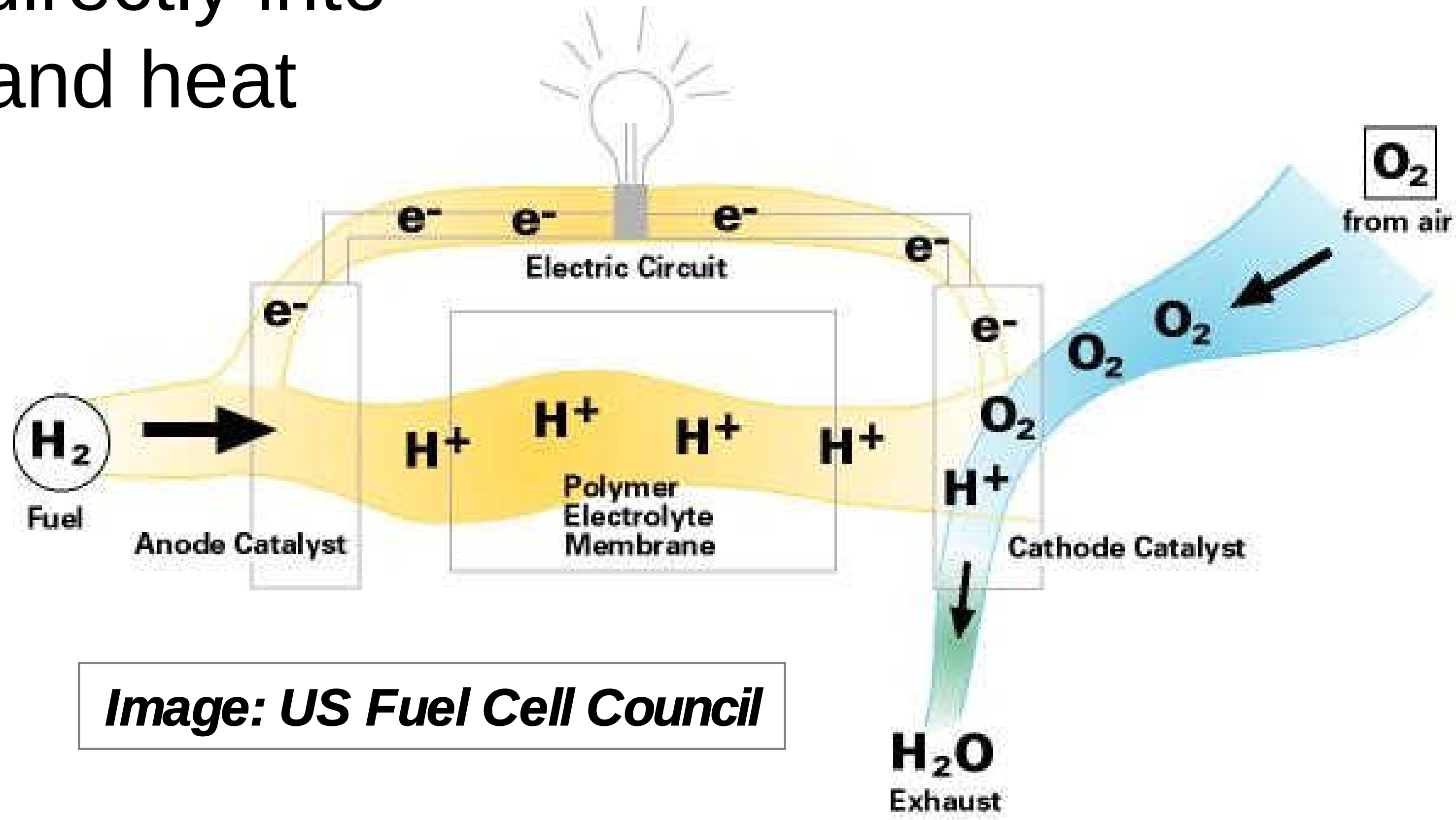

Image: US Fuel Cell Council

The structure of a PEM fuel cell

Polymer electrolyte membrane
and thin film electrodes,
~40 µm

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Gas diffusion layers,
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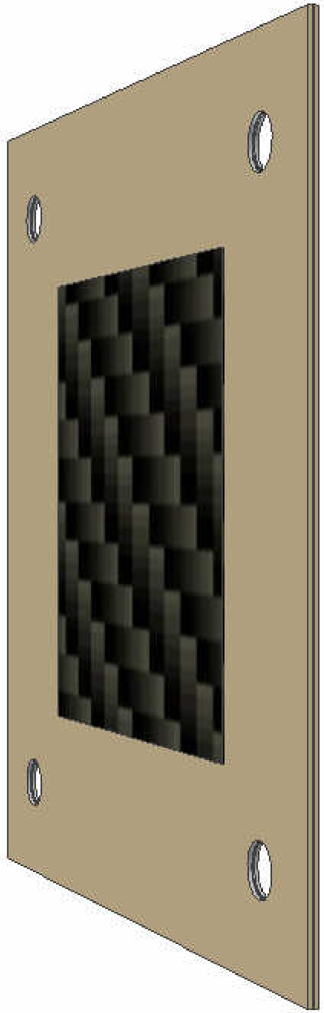
Gaskets



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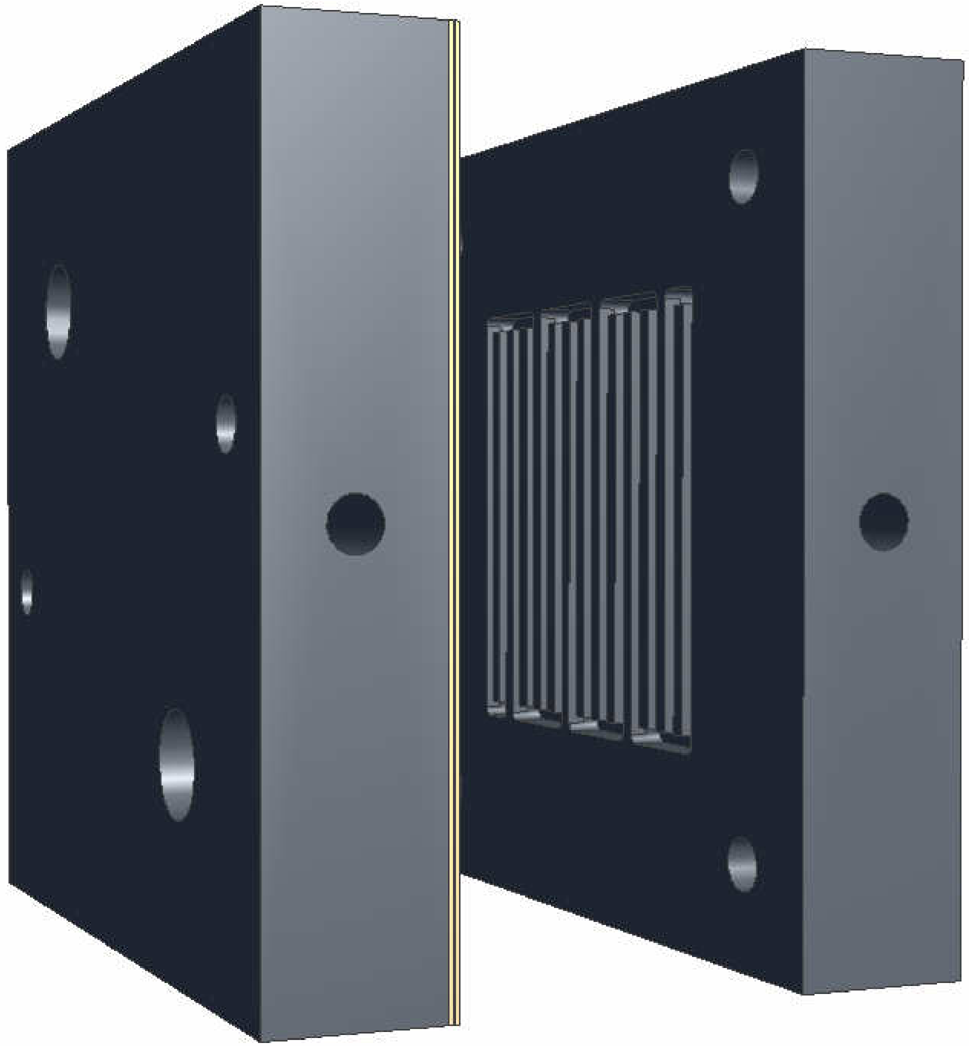
Flow field plates



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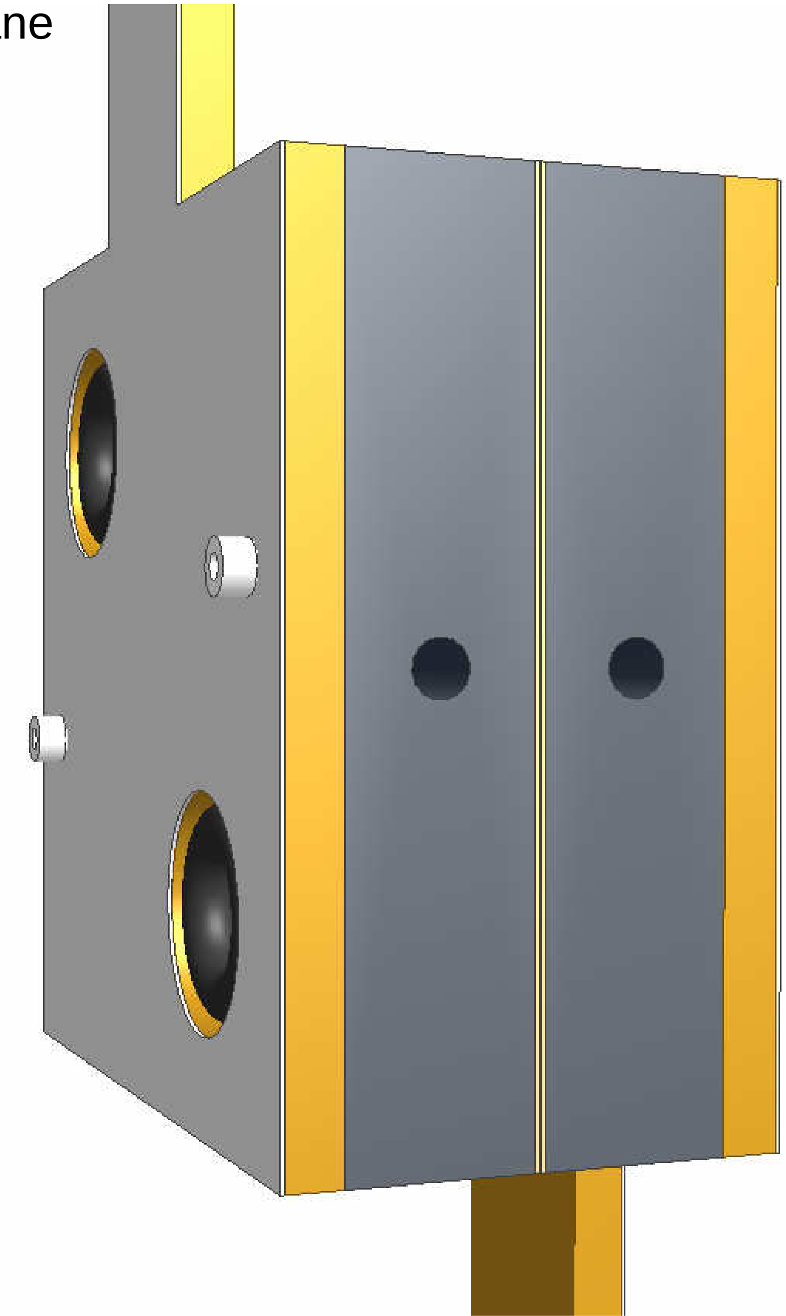
Current collectors



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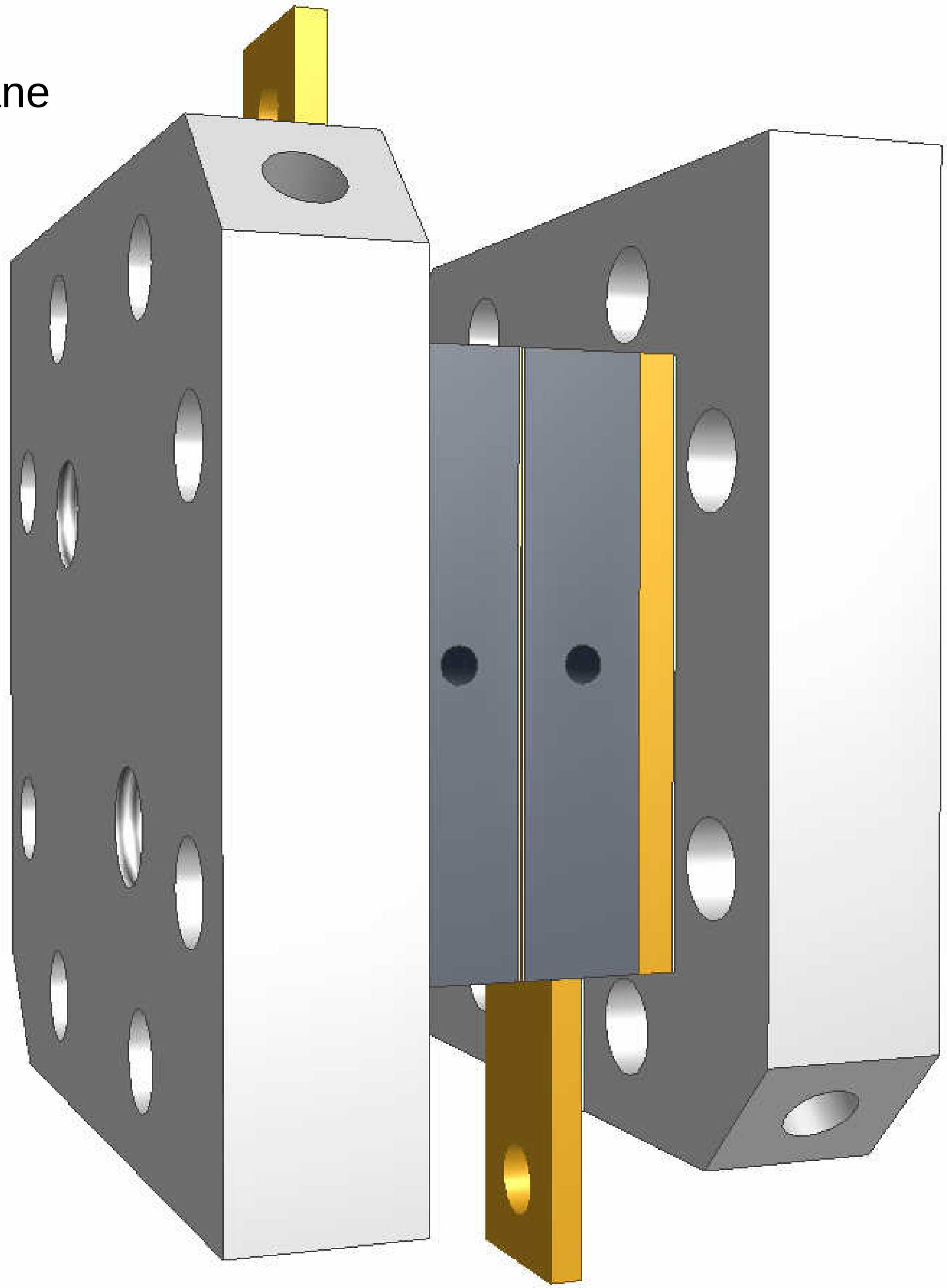
End plates



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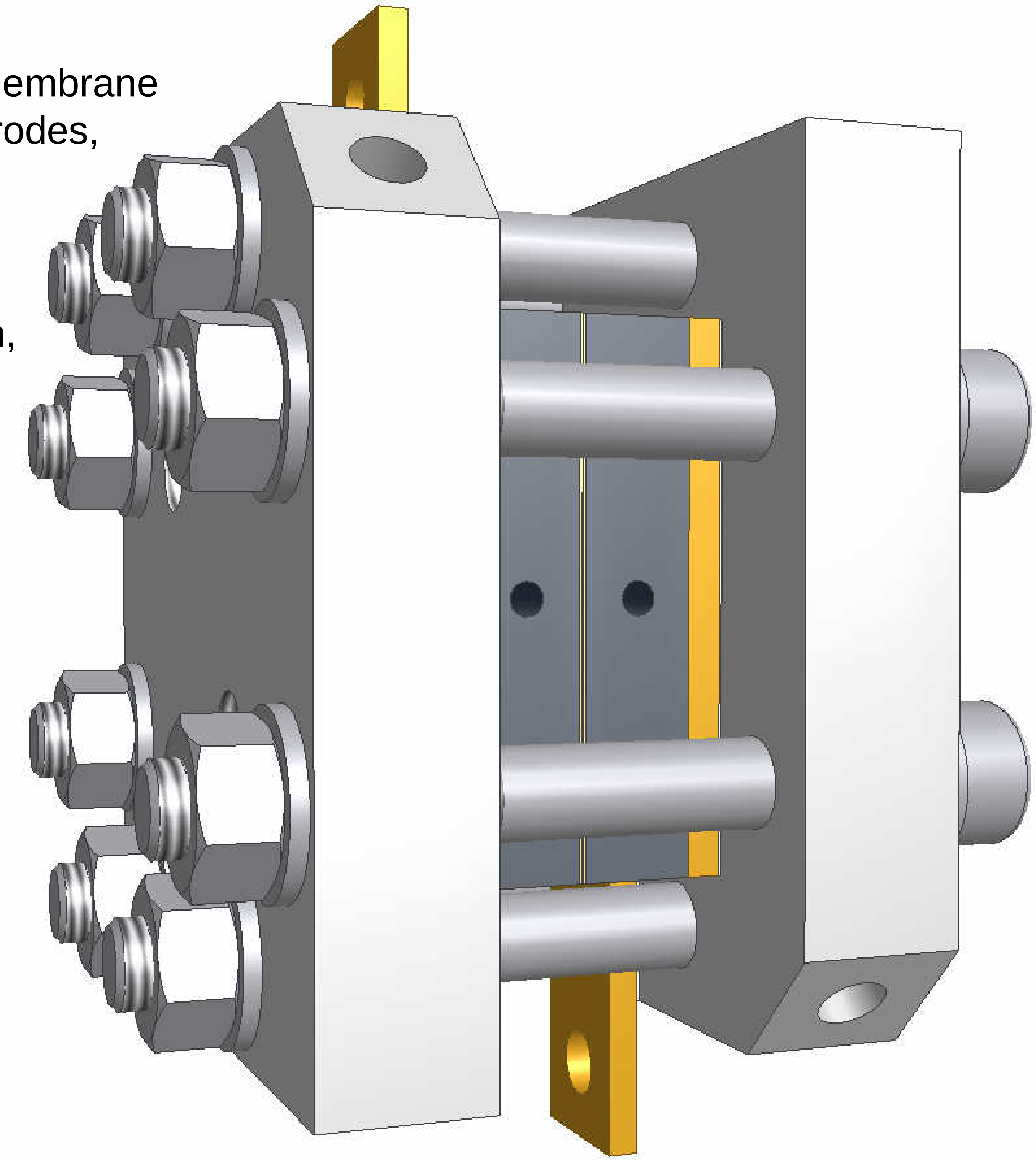
Clamping bolts



The structure of a PEM fuel cell

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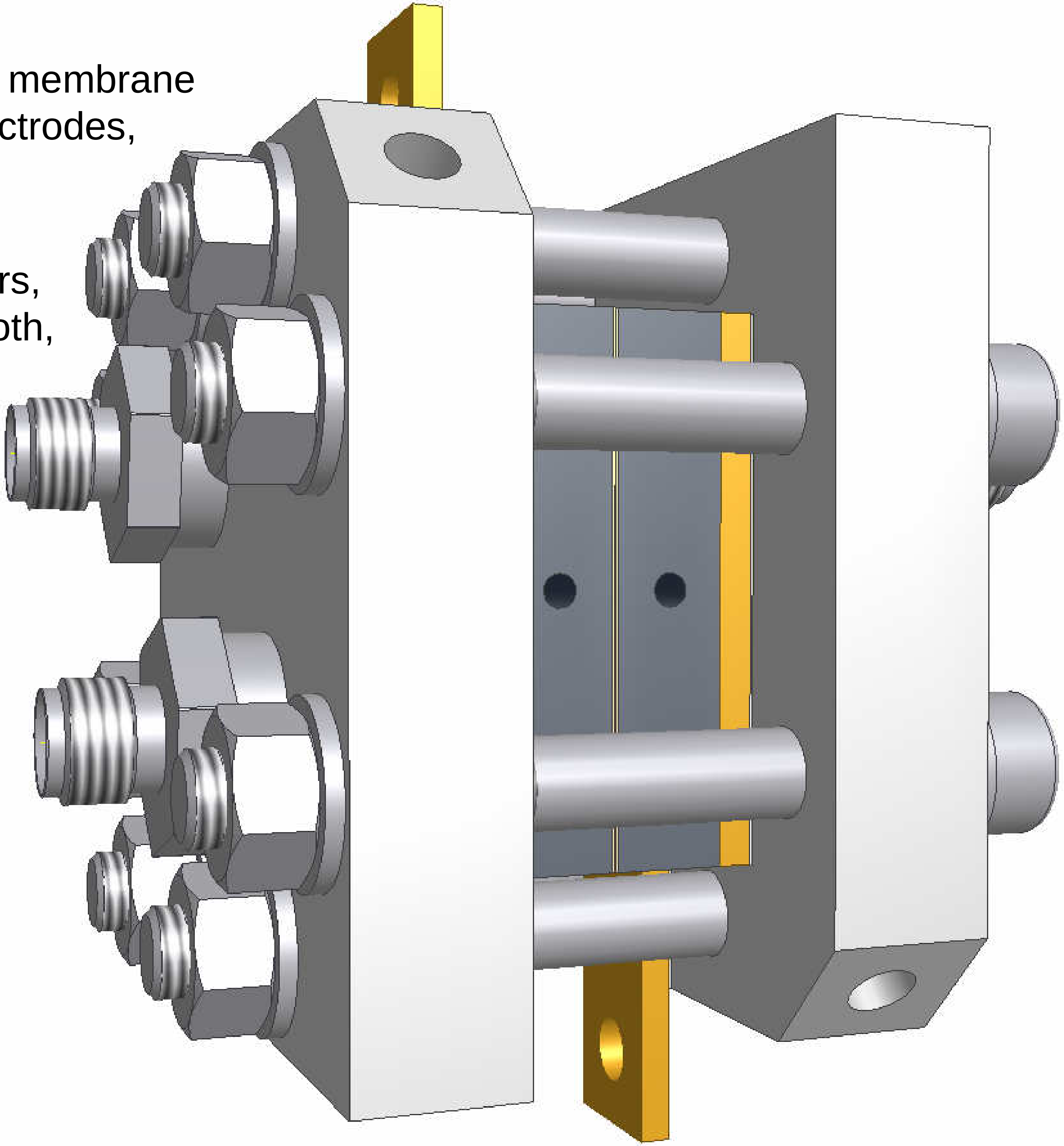
Clamping bolts

…and the rest



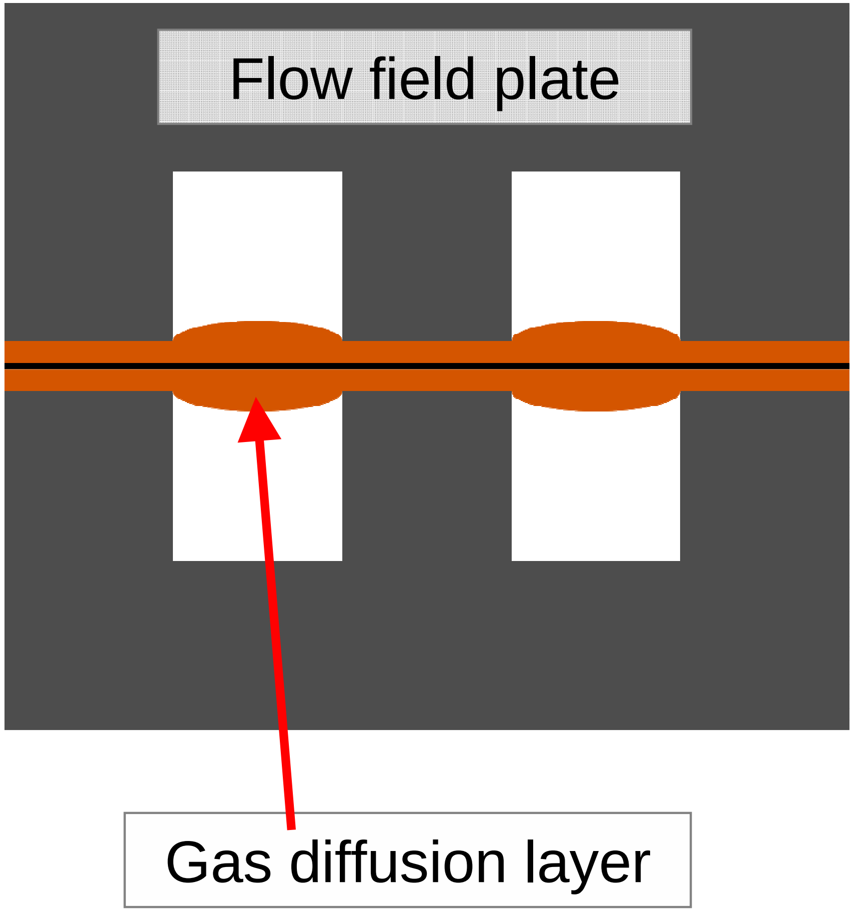
Significance of compression

- Low contact pressure increases electrical and thermal contact resistance
- High contact pressure hinders mass transfer resistance due to loss of porosity

➔ Finding optimal compression is a balancing act!

- The pressure distribution is rarely uniform
  - On millimeter scale
    - Ridge-channel structure
  - On larger scale
    - Clamping from the edges

Cell cross section view



Background and goals

- Measuring compression pressure distribution is laborious and can be done only close to room temperature
- Modeling provides a faster and cheaper way to predict the pressure distribution
  - Provided that a valid model and material parameters are available
- We have a model for that!
- Here, we demonstrate
  - A method to even out the pressure distribution
  - The effect of temperature on the pressure distribution

The physics

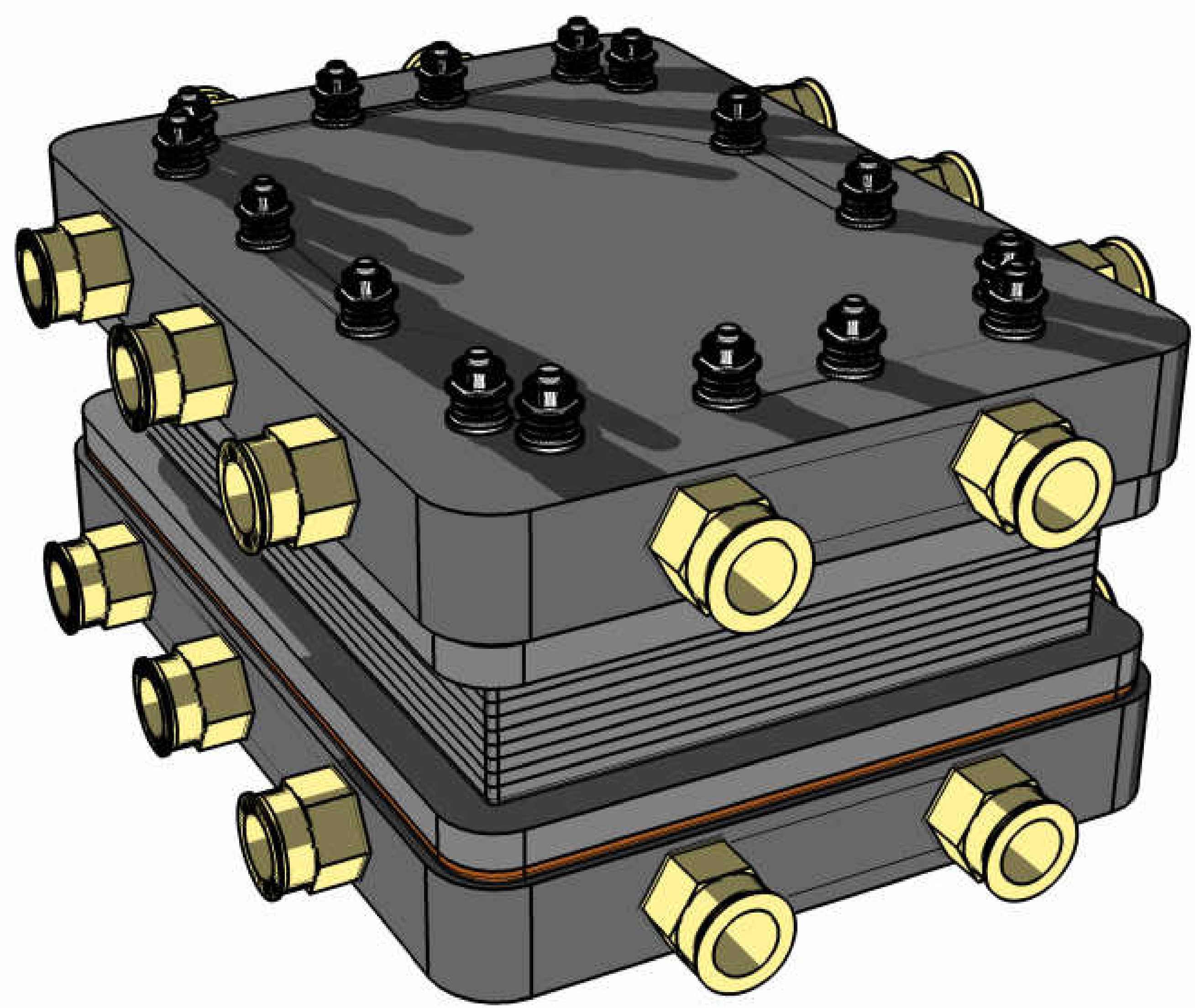
$$\nabla \cdot \left(D \nabla \mathbf{u} \right) = 0$$

$$D = \frac{E}{(1+\ \ )(1-2\ \ )} \begin{bmatrix} 1- & & & 0 & 0 & 0 \\ & 1- & & 0 & 0 & 0 \\ & & 1- & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{2}- & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2}- & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{2}- \end{bmatrix}$$

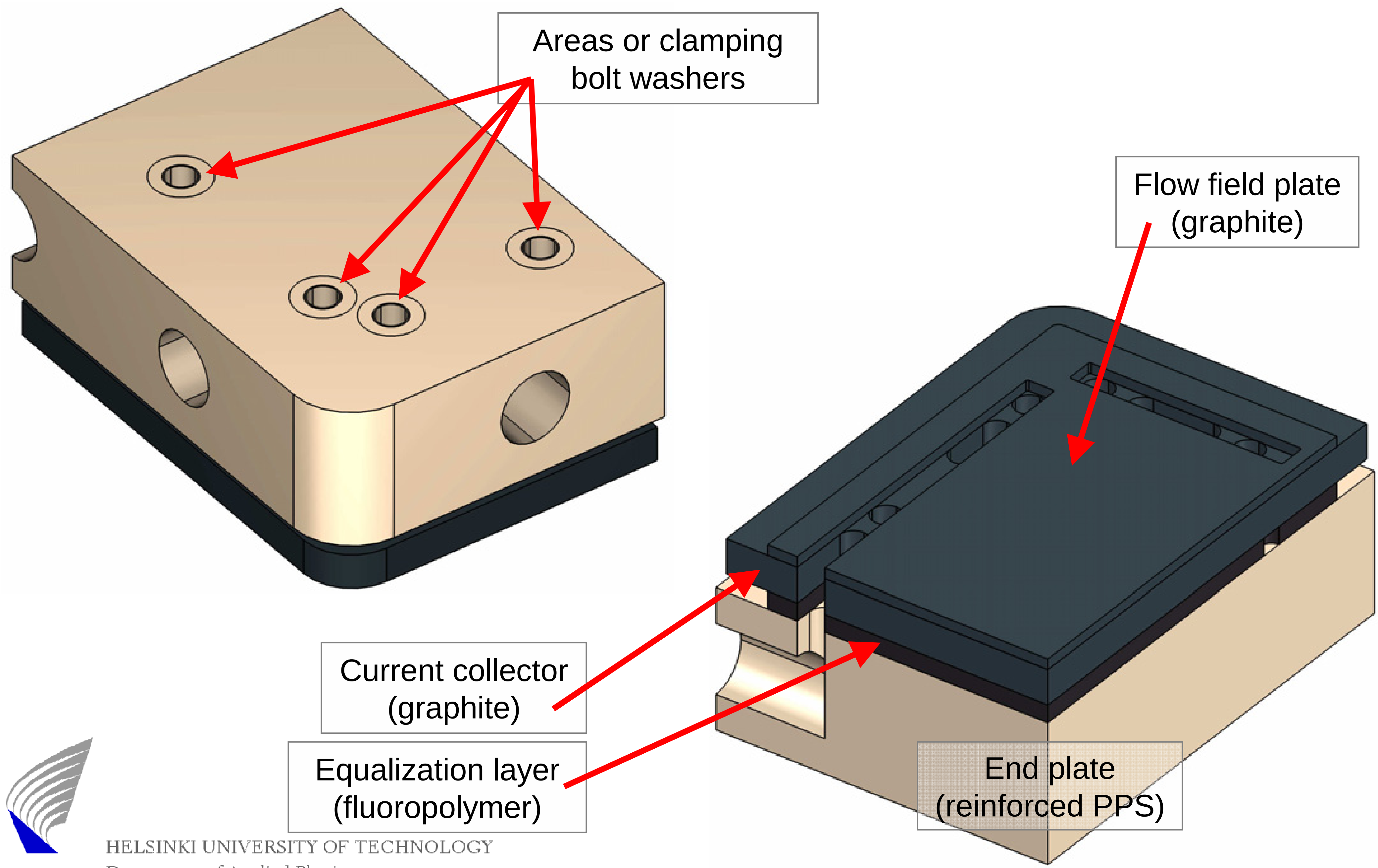
- Solid, Stress-Strain application mode
  - Isothermal, linear elasticity, isotropic materials
  - Input measured Young’s moduli and Poisson’s ratios
  - Solved for displacement field **u**
- Boundary conditions
  - Clamping force as a area load around the bolt holes
  - Symmetry conditions where applicable
  - A contact pair condition between rigid components

The model

- Model geometry fashioned after an existing fuel cell stack



Model subdomains



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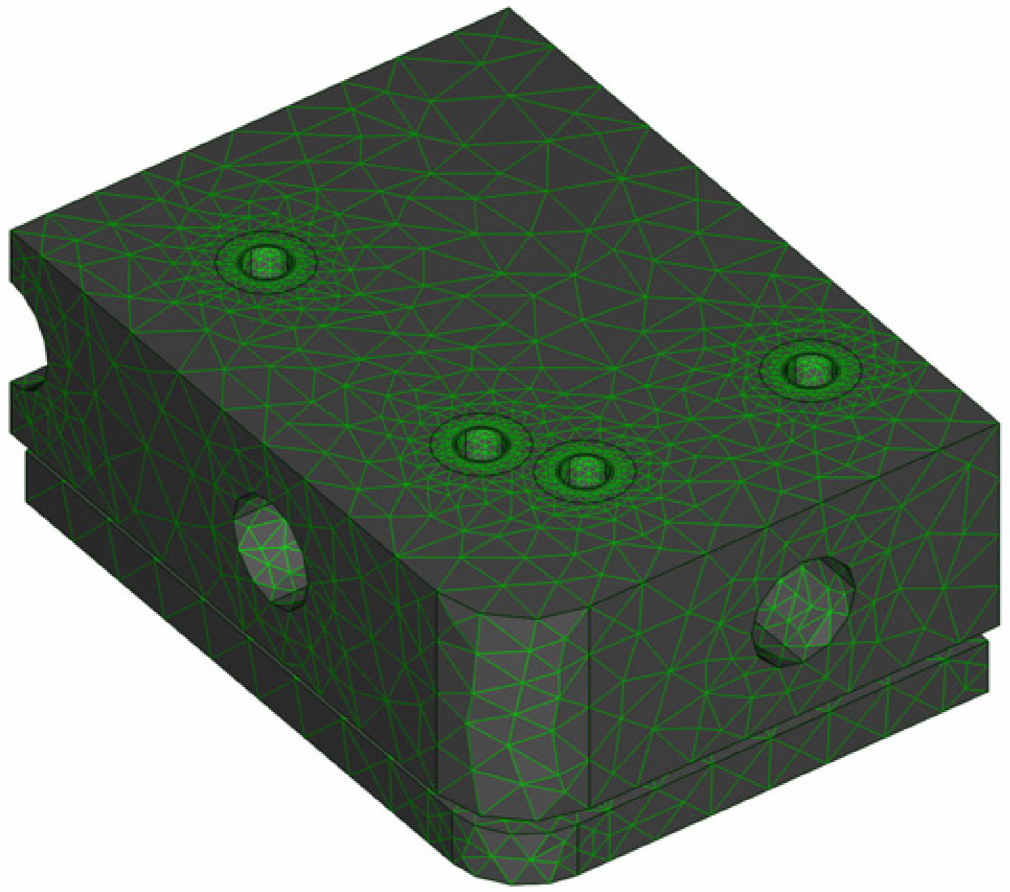
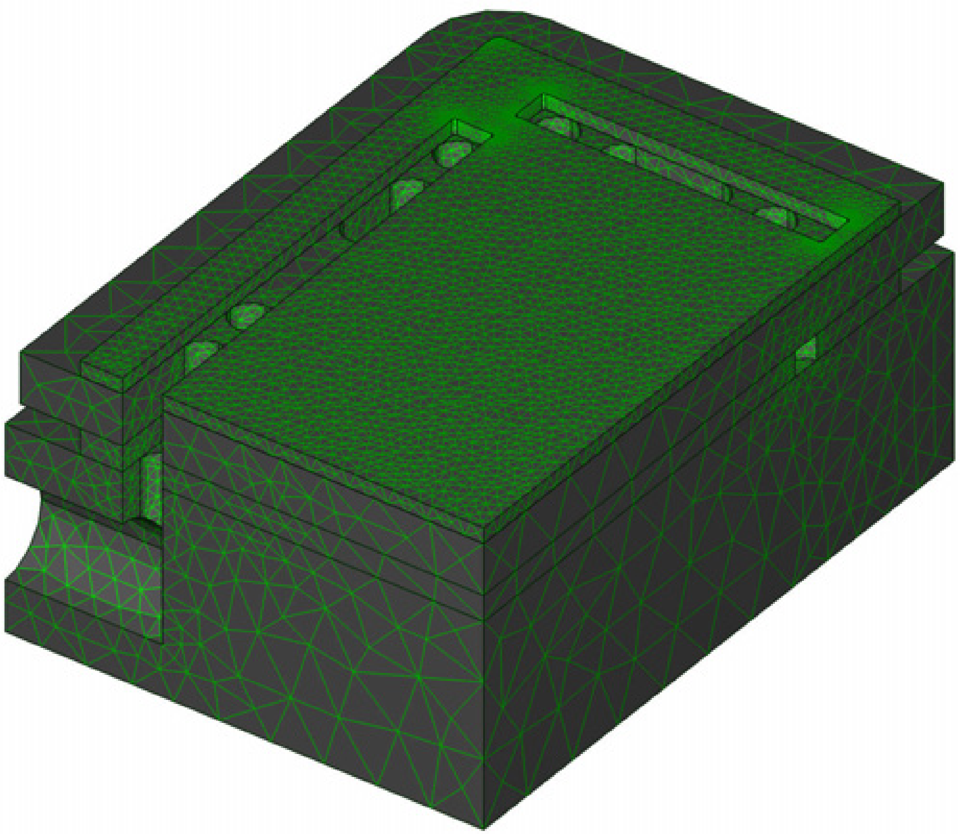
The mesh



- ~200k tetrahedral mesh elements
- ~420k degrees of freedom,
- ~4 h solution time with PARDISO solver on an Intel Core 2 Quad Q9550 + 8 GB RAM



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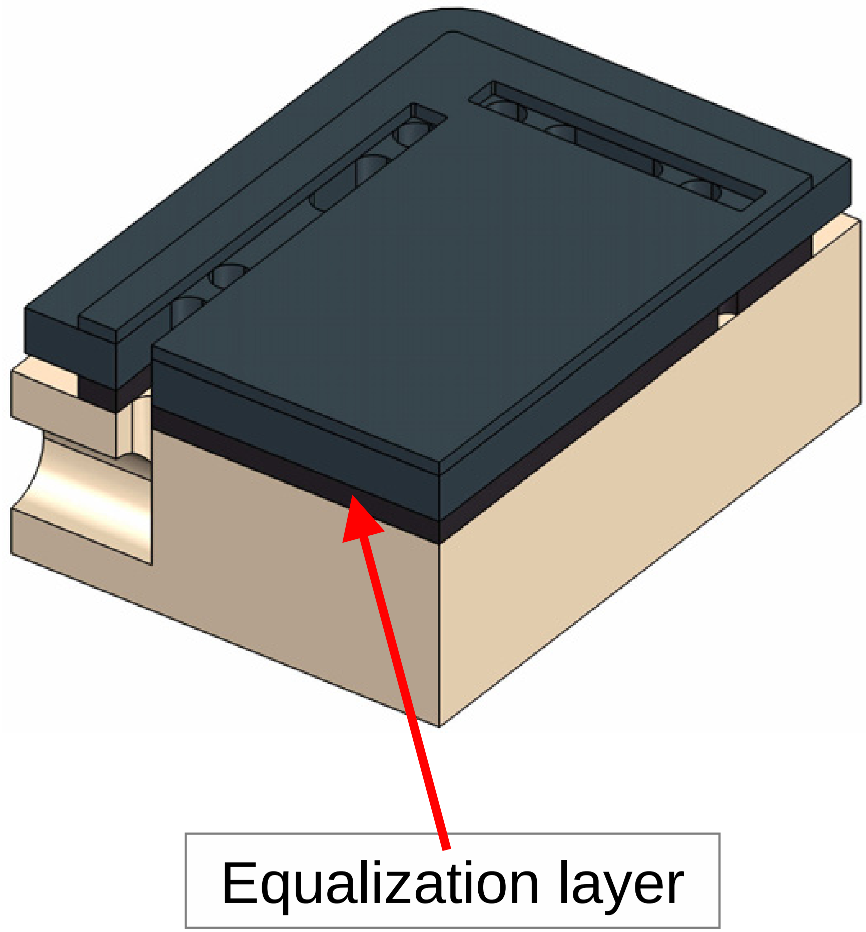
Modeled case 1

The effect of the pressure equalization layer

- A 5 mm fluoropolymer layer between the end plate and current collector evens out the variations in clamping force
- The equalization layer is much softer than the other components

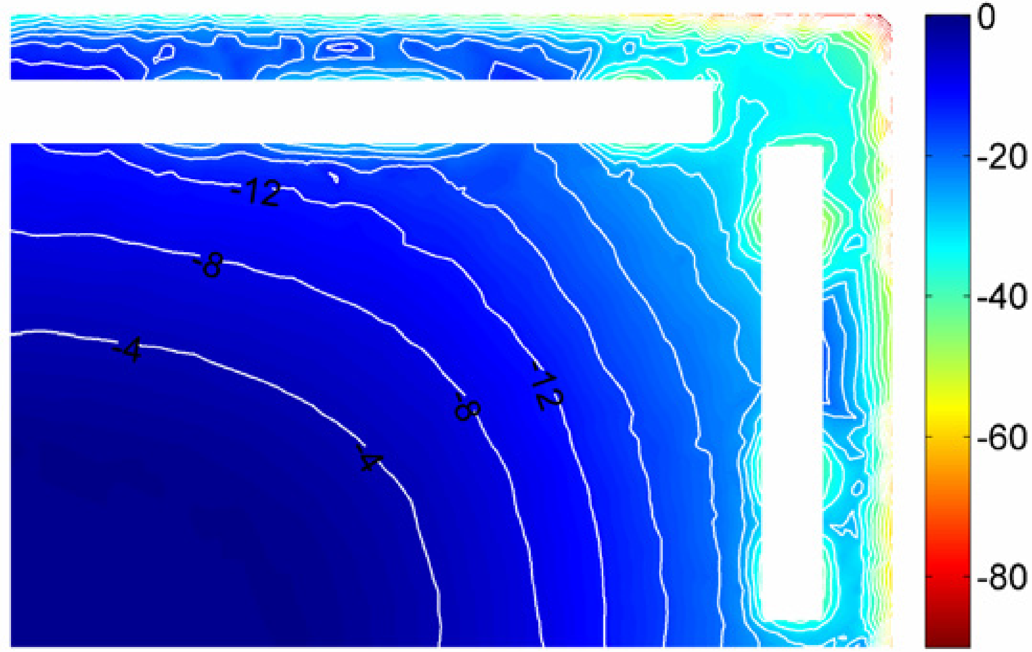


Modeled case 1

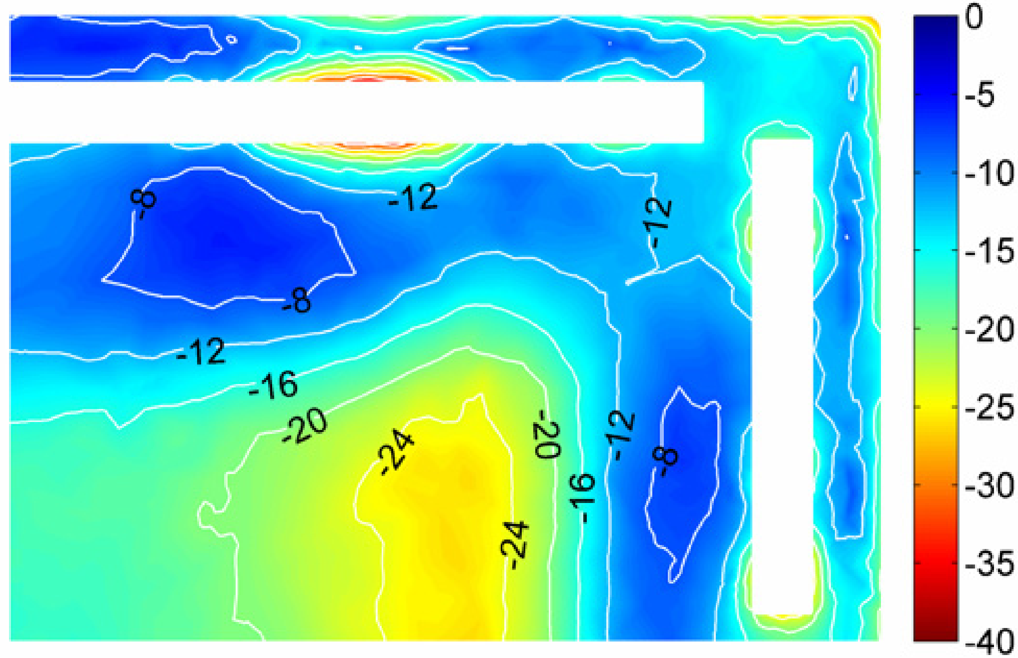
The effect of the pressure equalization layer

Pressure distribution on the flow field plate surface

Without equalization layer



With equalization layer



Pressure unit: bar

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Modeled case 2
The effect of temperature

- Young's moduli depend on temperature

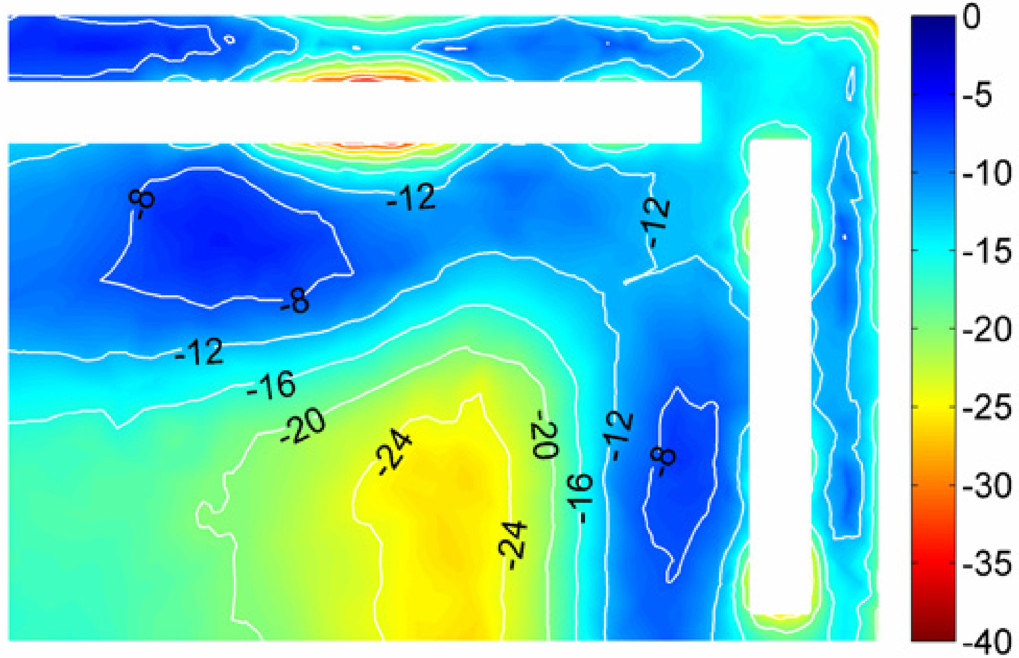
T (°C)	Graphite		Fluoropolymer		PPS + 40% GF	
	E (GPa)	Change (%)	E (MPa)	Change (%)	E (GPa)	Change (%)
23	**2.10** ± 0.05	0	**12.96** ± 0.47	0	**13.07** ± 0.25	0
80	**2.16** ± 0.03	2.7	**7.89** ± 0.28	-39.1	**11.01** ± 0.25	-15.8
120	**2.08** ± 0.04	-1.3	**8.08** ± 0.28	-37.7	**7.17** ± 0.25	-45.1
160	**1.64** ± 0.16	-22.2	**8.96** ± 0.27	-30.9	**5.29** ± 0.25	-59.5

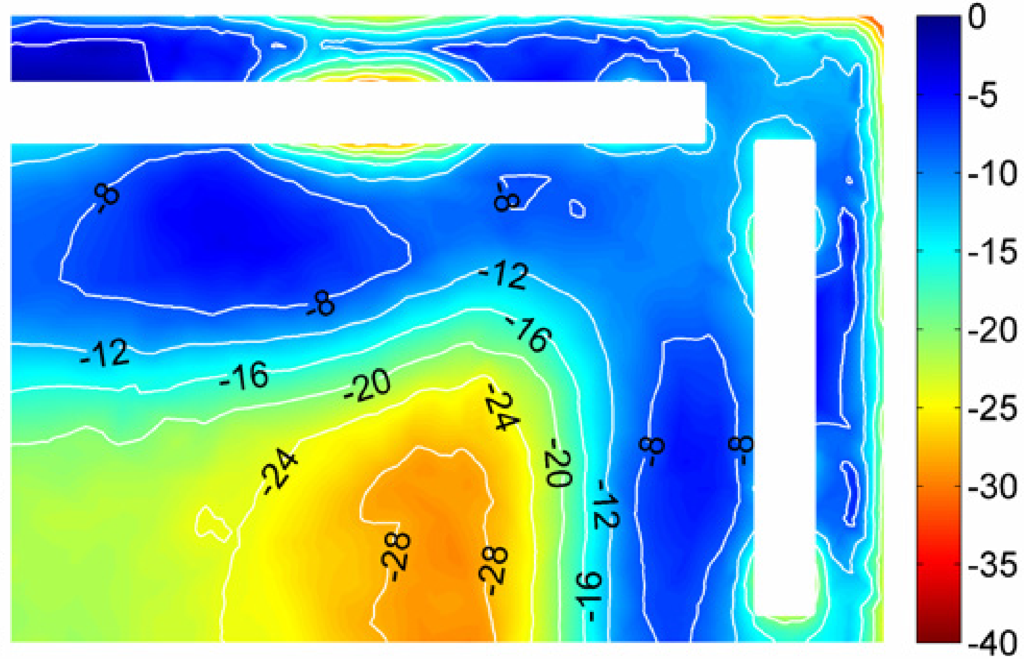
Modeled case 2

The effect of temperature

Pressure distribution on the flow field plate surface

At 23 ° C	At 160 °C





Pressure unit: bar

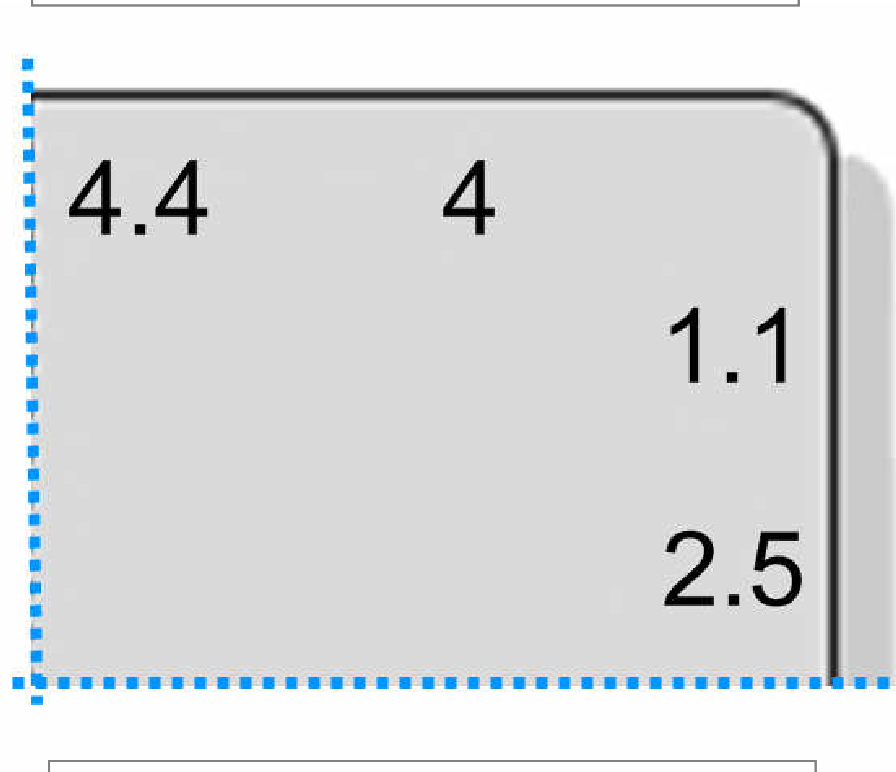
Conclusions

- Thermal expansion is not significant at these temperatures
- The equalization layer really makes a difference!
- Uniformity of pressure distribution at assembly temperature not enough!
  - Softening of cell components with increasing temperature leads into more uneven pressure distribution
- This model can be used for optimizing clamping systems also for high temperature fuel cells provided that material data is available


That's all Folks!

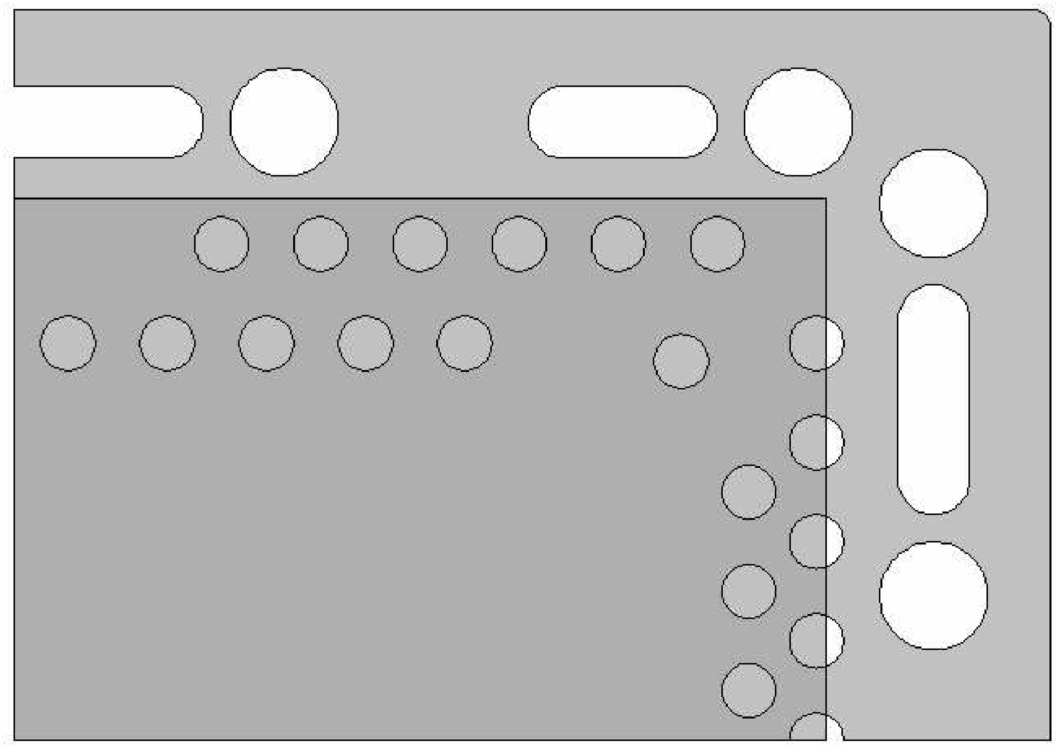
Bonus slide 1: Geometry details

Clamping force scheme



Force per bolt in kN.

The geometry of the pressure equalization layer



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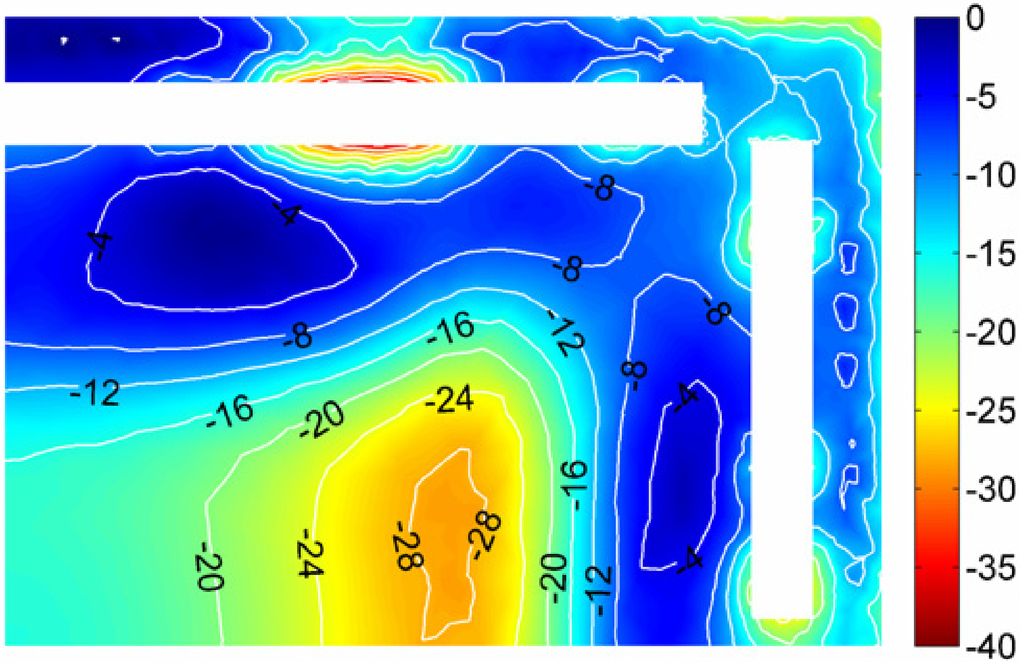
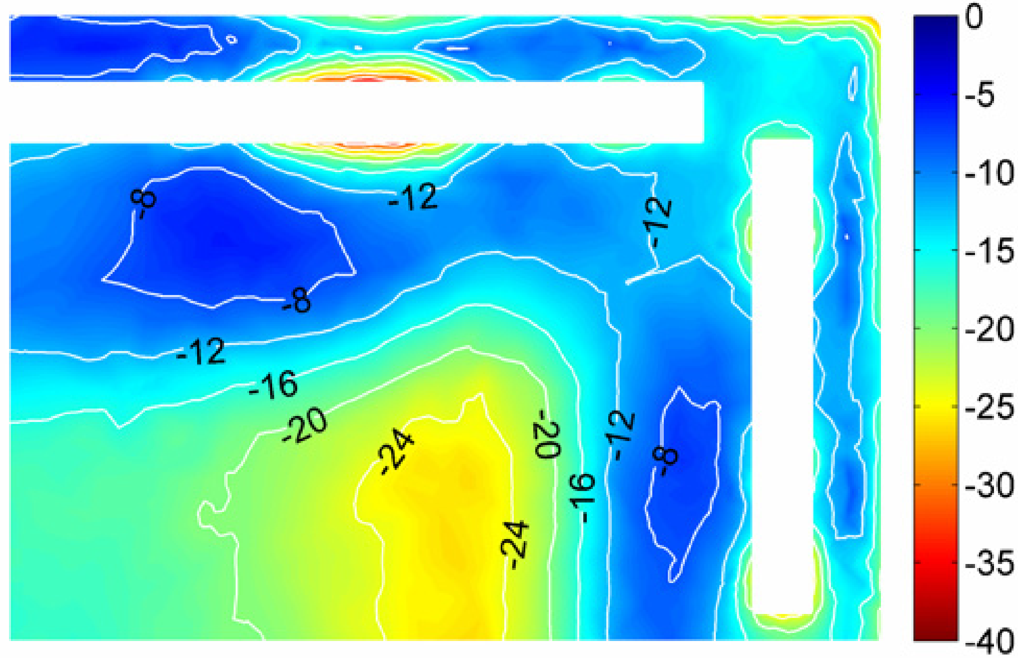
Bonus slide 2: The effect of the contact pair boundary condition

Without contact pair



With contact pair



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