Institute for Power Electronics and Electrical Drives
RWTH AACHEN

Modeling of HTPEM Fuel Cell Start-Up Process by Using Comsol Multiphysics

Comsol Conference Europe 2012

23.10.2012

Yu Wang, Julia Kowal, Dirk Uwe Sauer

Electrochemical Energy Conversion and Storage Systems Group, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University, Germany

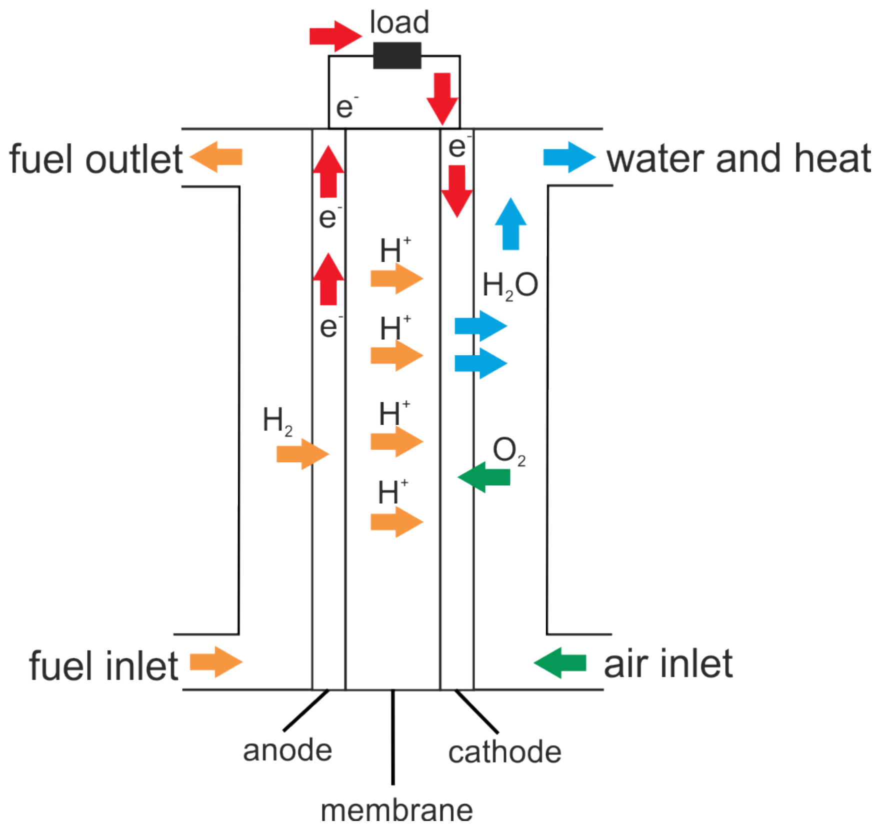
batteries@isea.rwth-aachen.de

Federal Ministry of Education and Research

COMSOL CONFERENCE EUROPE 2012

Excerpt from the Proceedings of the 2012 COMSOL Conference in Milan

Principle of PEM fuel cell



- Anode reaction: $H_2 = 2H^+ + 2e^-$
- Cathode reaction: $O_2 + 4H^+ + 4e^- = 2H_2O$

$$2H_2 + O_2 = 2H_2O$$

Motivation

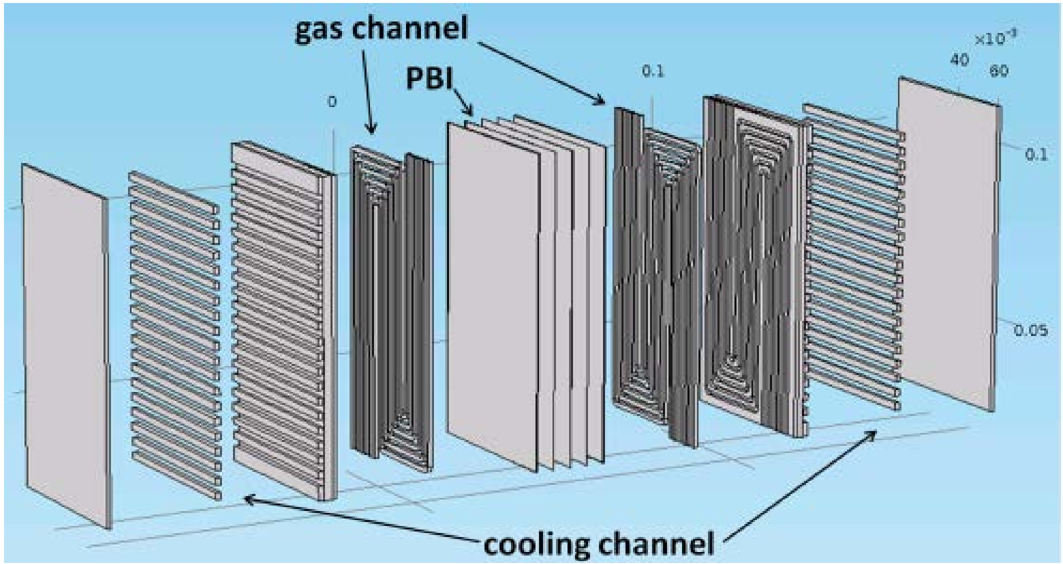
Institute for Power Electronics and Electrical Drives
RWTH AACHEN

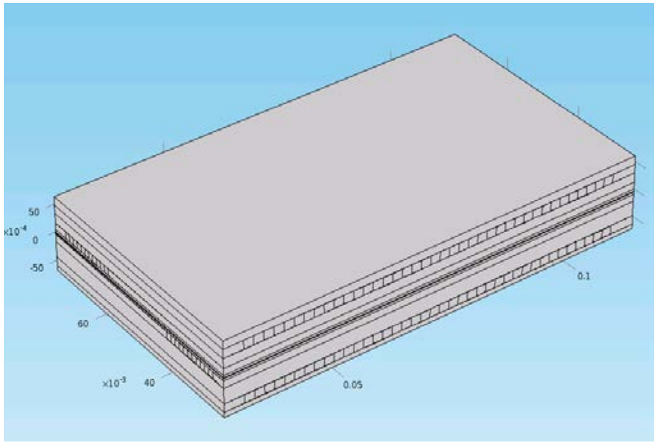
- Why **h**igh **t**emperature **p**roton **e**xchange **m**embrane (HTPEM) fuel cell
  - Enhanced electrochemical kinetics than low temperature PEM fuel cell
  - No water management needed
  - Higher CO tolerance – integrating fuel cell with fuel processing unit (e.g. reformer) possible

Room temperature → **Operation temperature: 160 – 180 °C**

- Study for different start-up methods

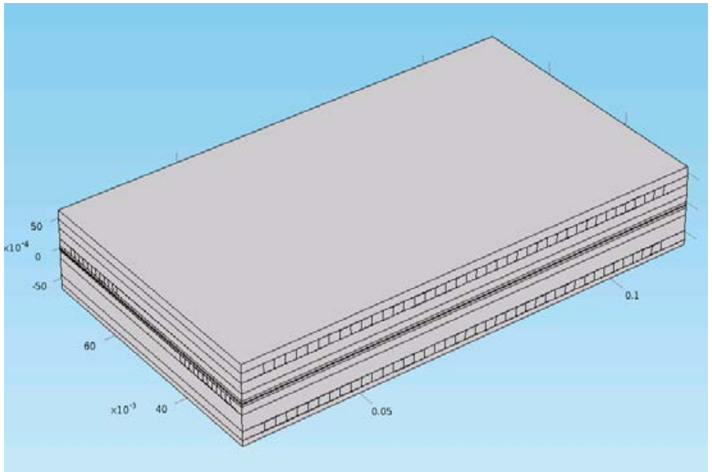
Cell structure

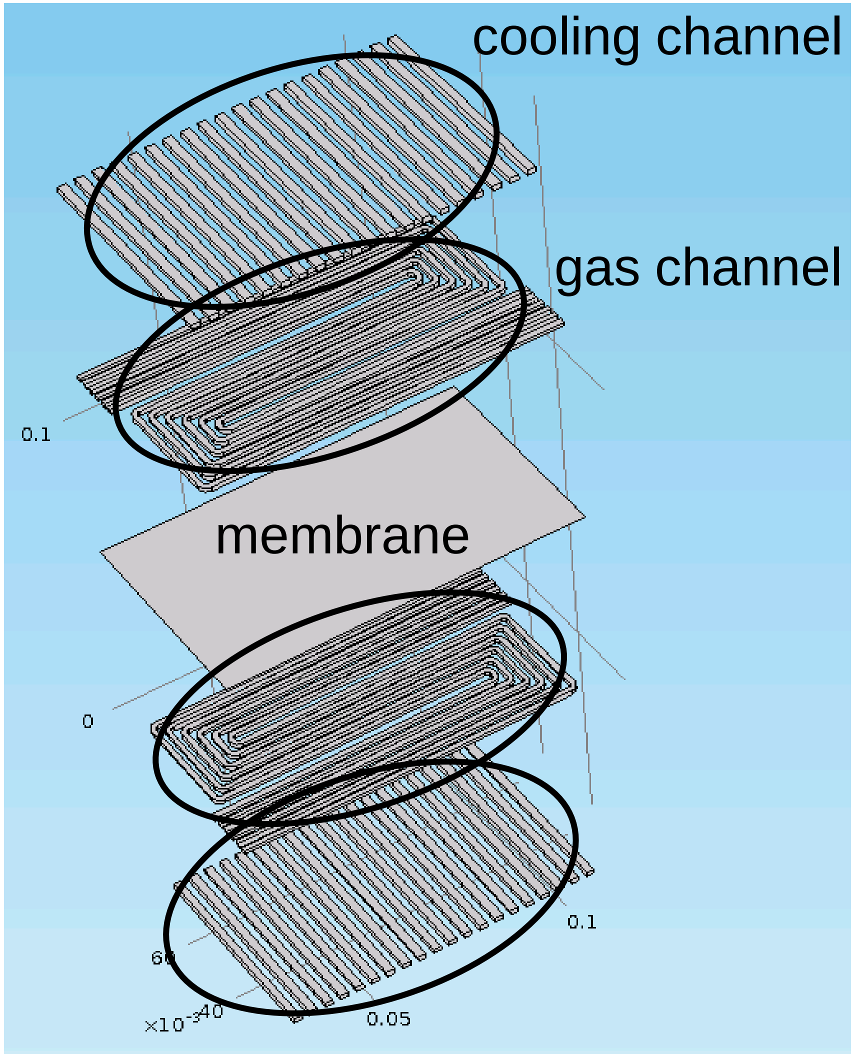




- PBI (polybenzimidazole) membrane
- Active area: 90 x 50 mm^2

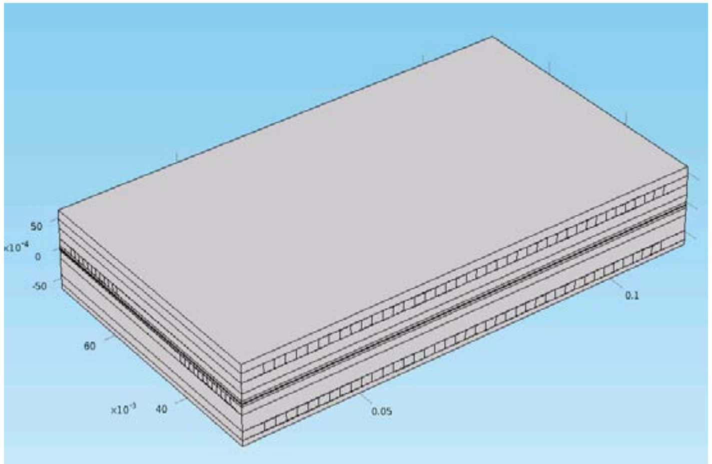
Channel structure

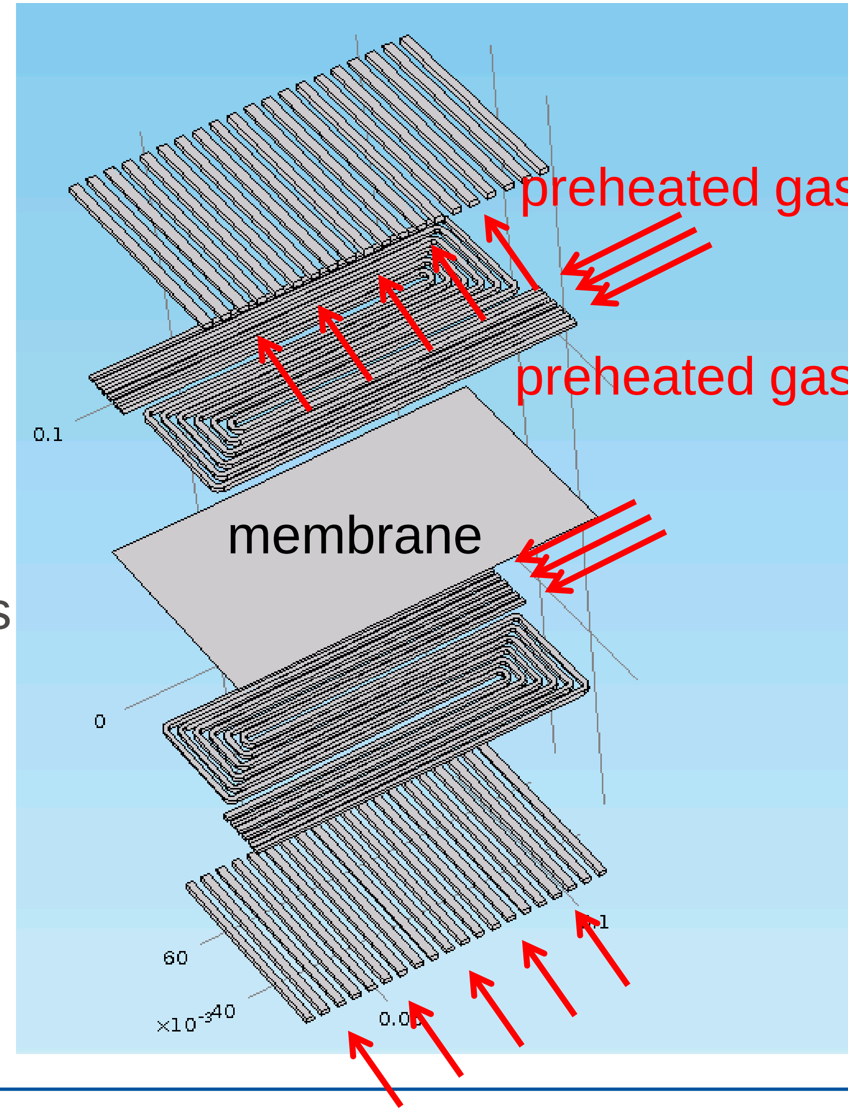




- Gas channel: (1.2 x 1.2 mm^2) x 6
- Cooling channel: (1.5 x 2 mm^2) x 20

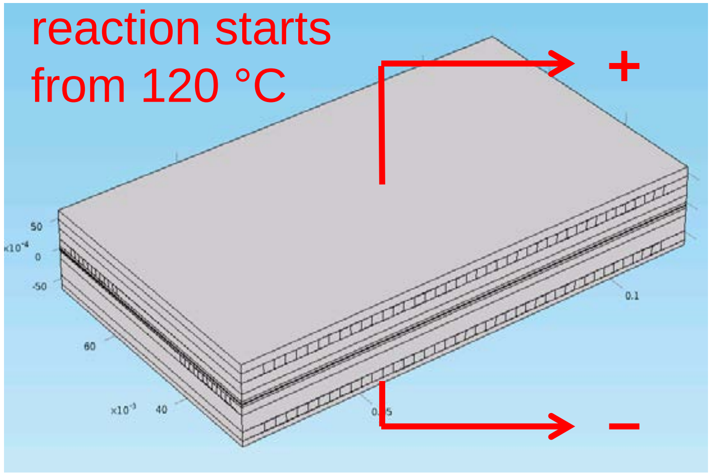
Different start-up methods

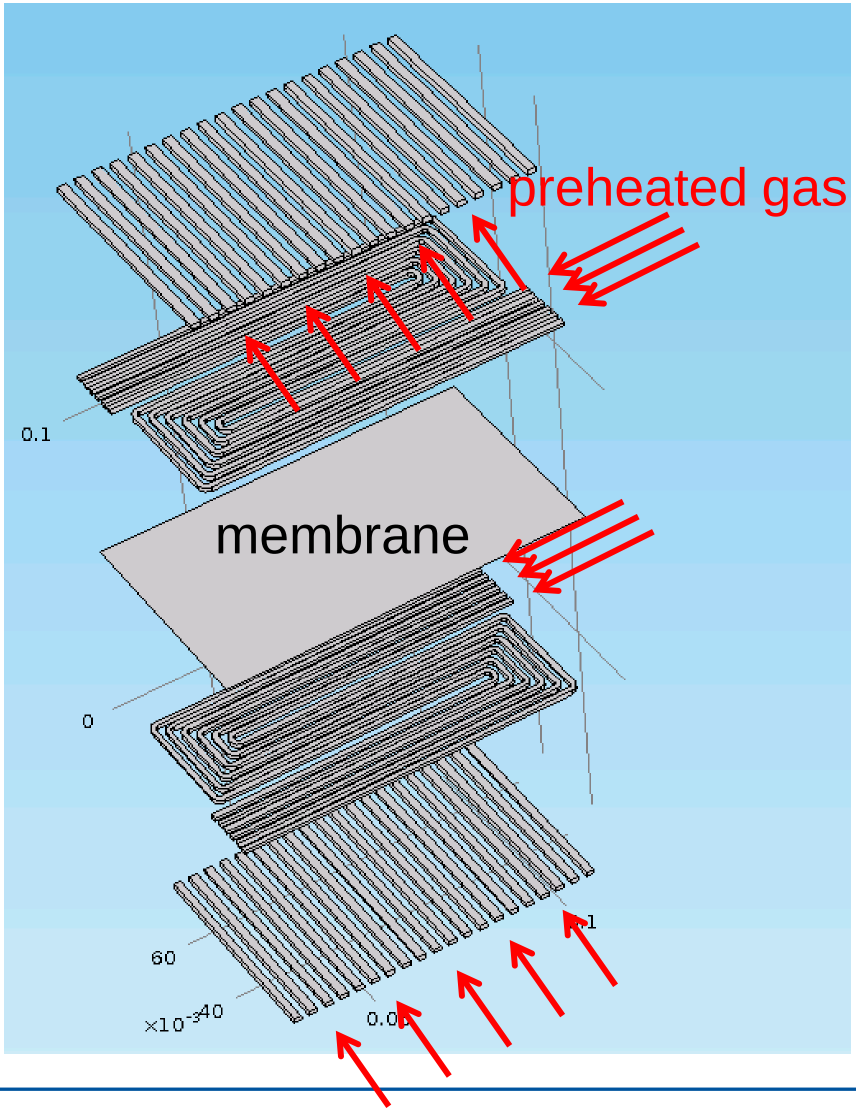




- Method 1: Heating by gas channels
- Method 2: Heating by cooling channels

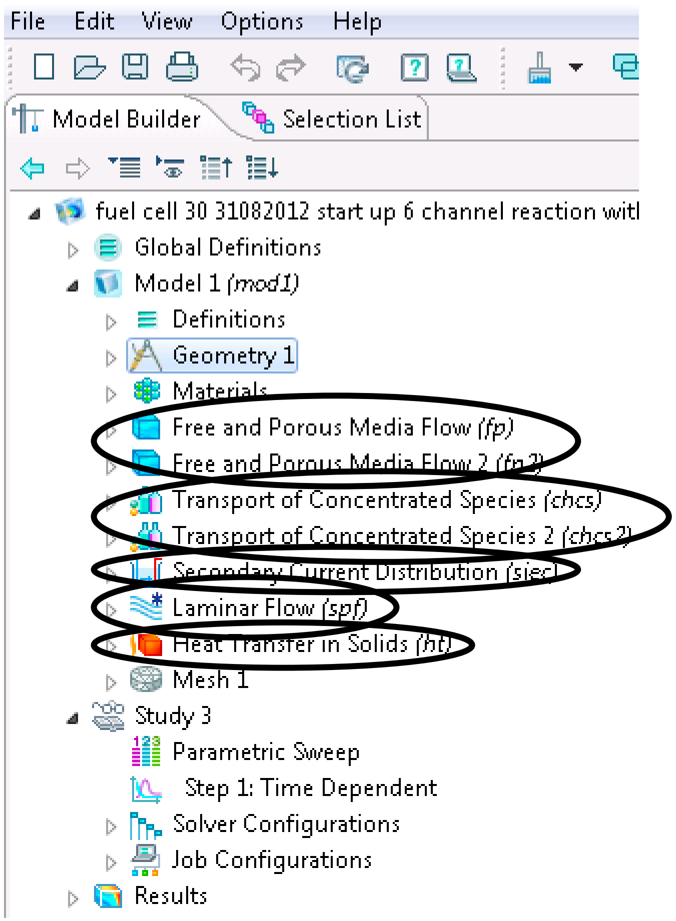
Different start-up methods





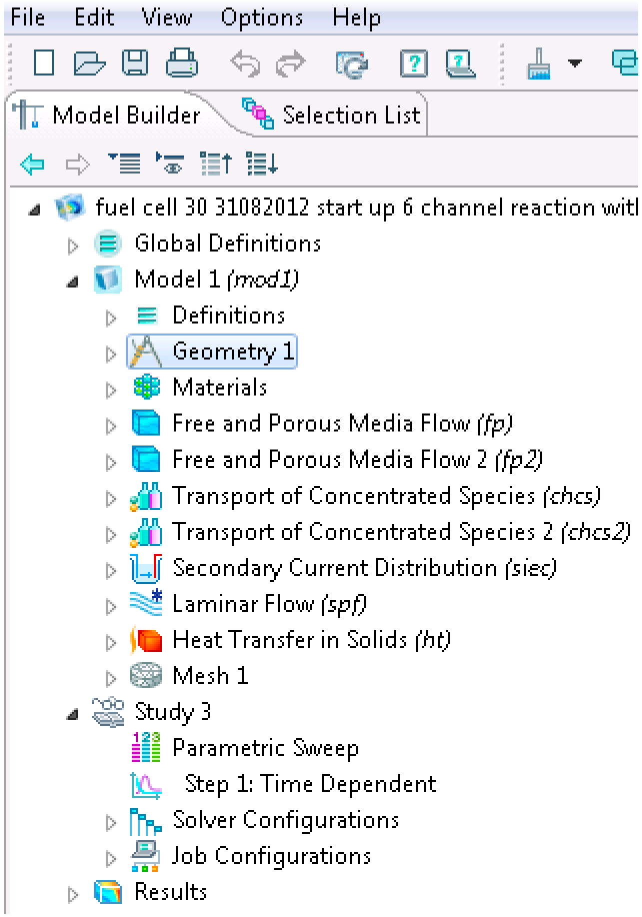
- Method 1: Heating by gas channels
- Method 2: Heating by cooling channels
- Method 3: Heating by gas channels, and then reaction (starts from 120 °C cell temperature)
- Method 4: Heating by cooling channels, and then reaction (starts from 120 °C cell temperature)

Physics



- Charge balances – Ohm‘s law
  - Ionic current
  - Electronic current
- Electrochemical behaviors – Butler-Volmer
  - Anode overpotential
  - Cathode overpotential
- Momentum transfer
  - Navier-Stokes equation in flow channels
  - Brinkman equation in porous gas diffusion layers
- Mass transfer - Maxwell-Stefan equation
  - Flow channels
  - Porous diffusion layers
- Heat transfer - in solid and fluid

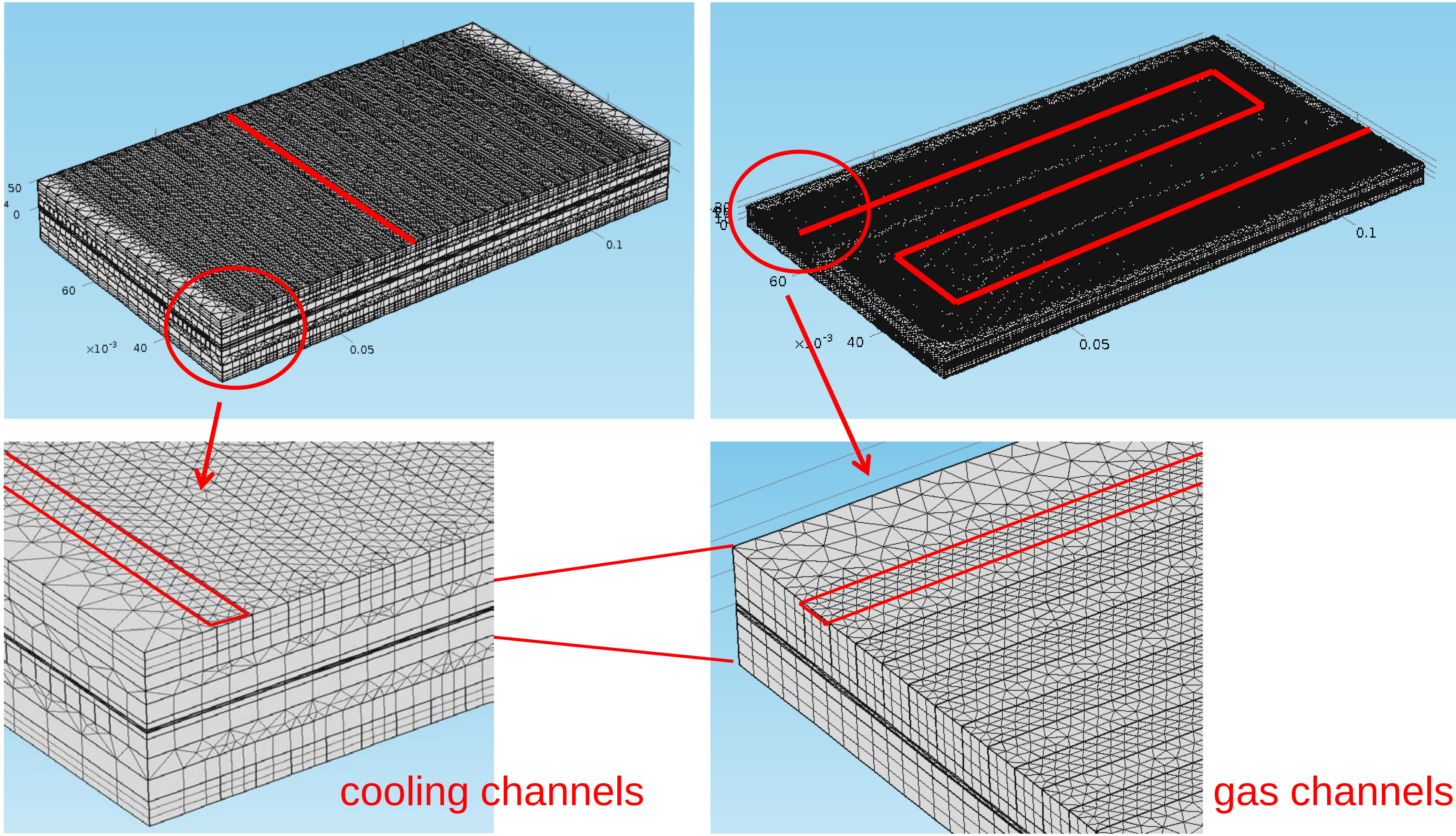
Important boundary conditions



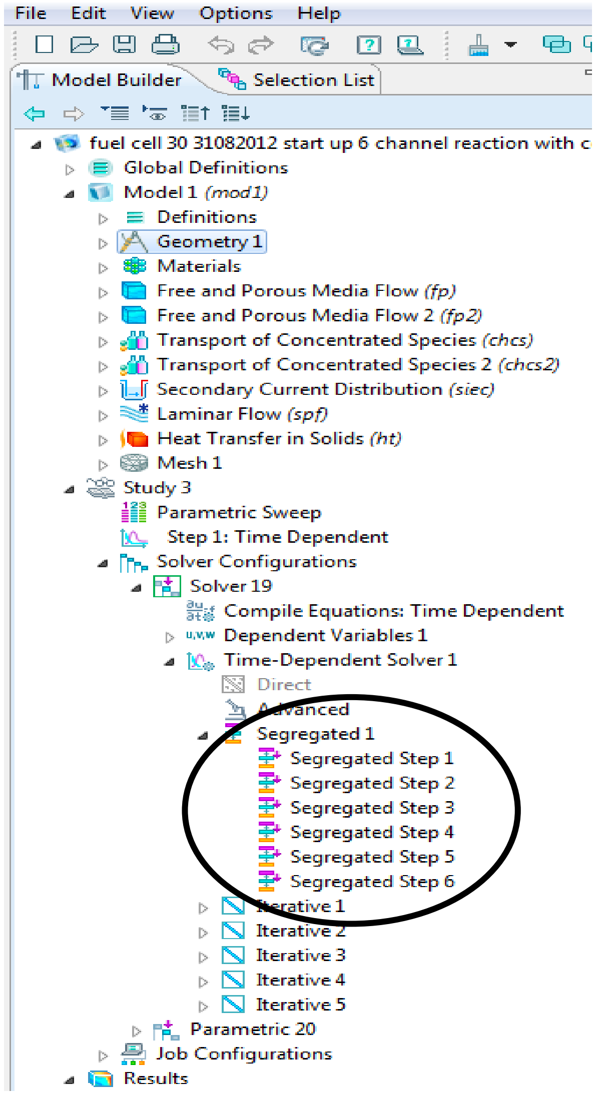
- Boundary conditions
  - Initial cell temperature: room temperature
  - Target cell temperature: 160 °C
  - Fuel cell insulated from environment

Mesh – 310,733 elements

Institute for Power Electronics and Electrical Drives
RWTH AACHEN

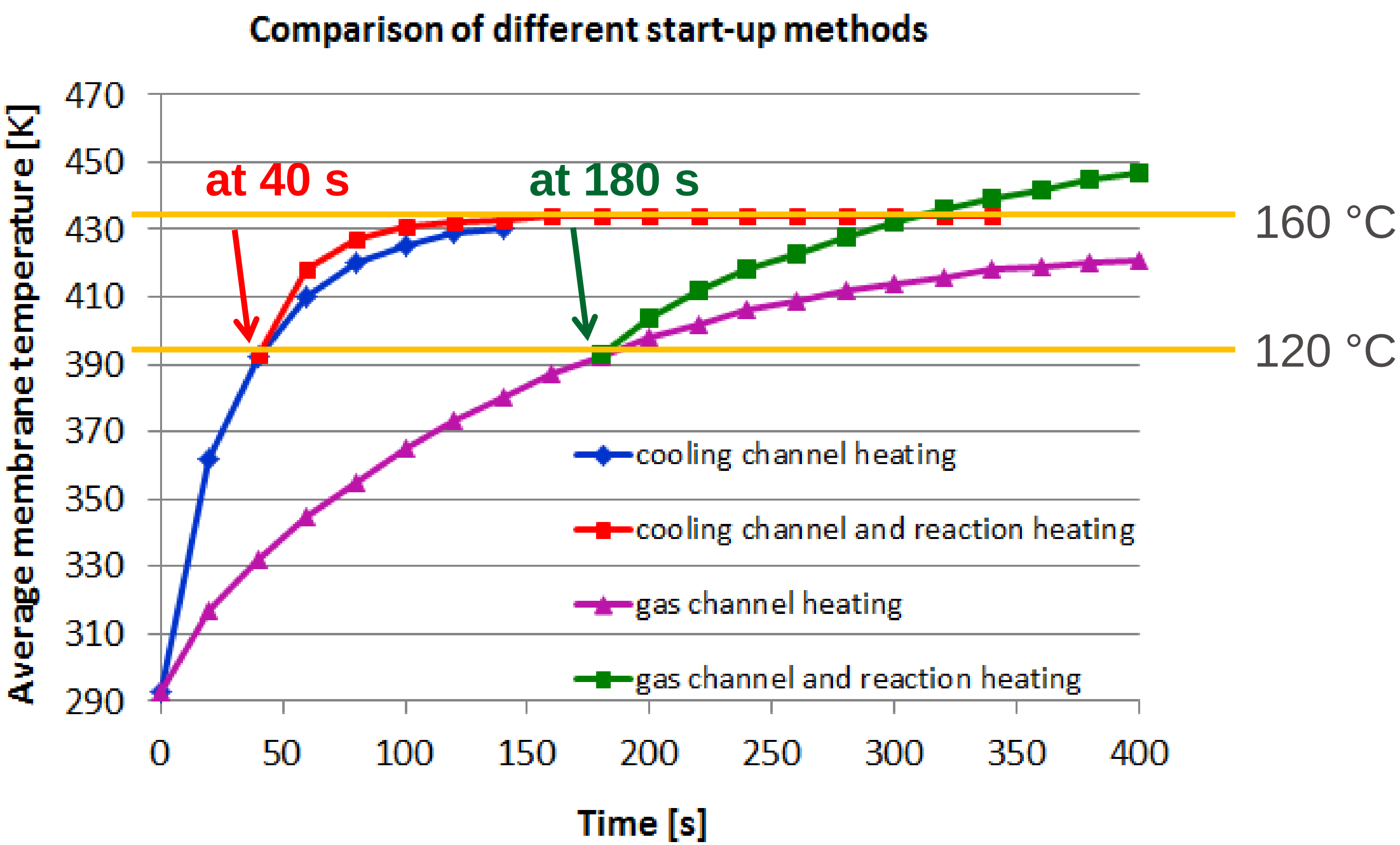


Solve the model



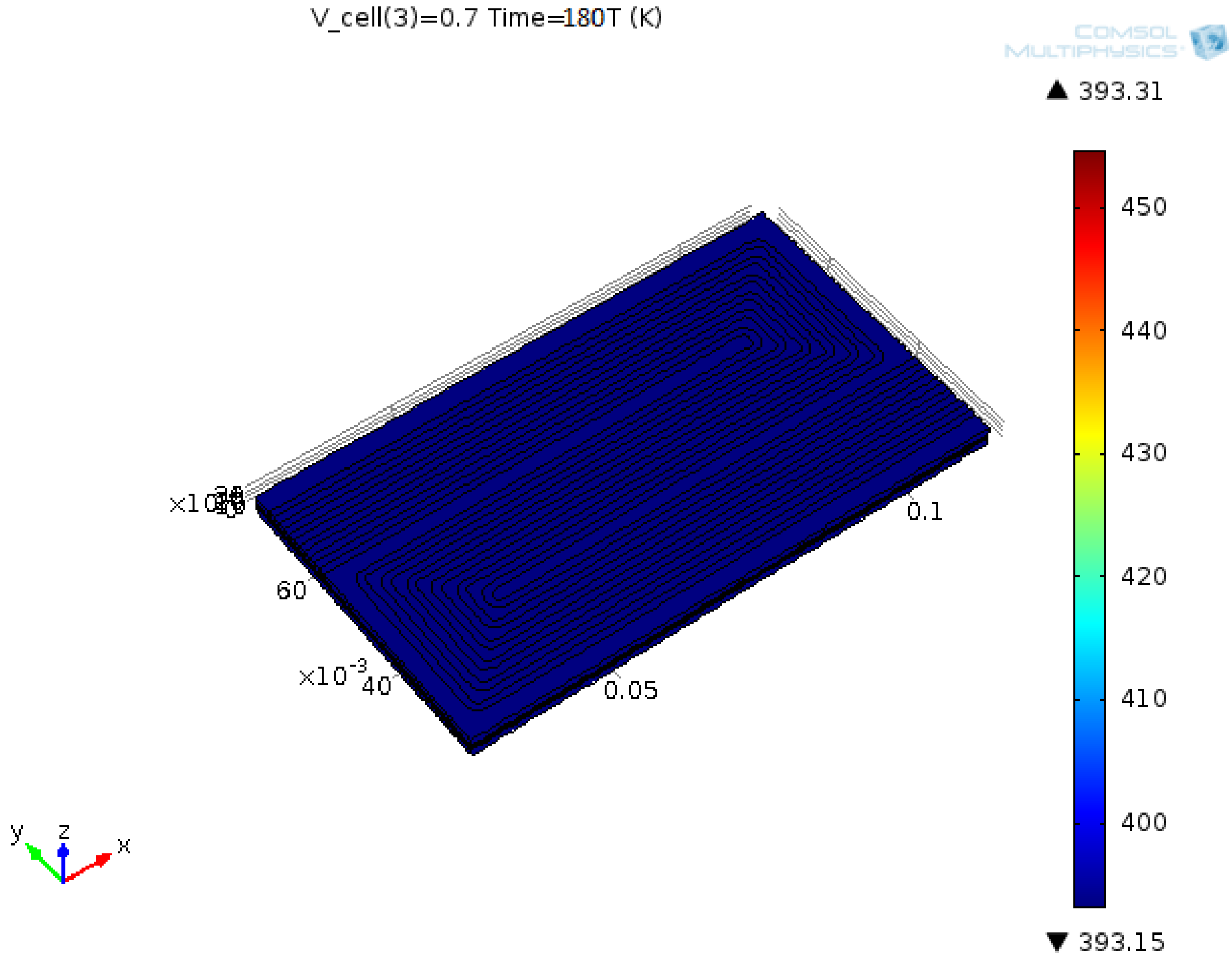
- To short simulation time, decrease RAM requirement and increase model convergence:
  - Set material parameters to be constant (no temperature dependence)
  - Use “step” function for “inlet” / “inflow”
  - Use segregated solver for each physics
  - Solve physics „heat transfer“ separately

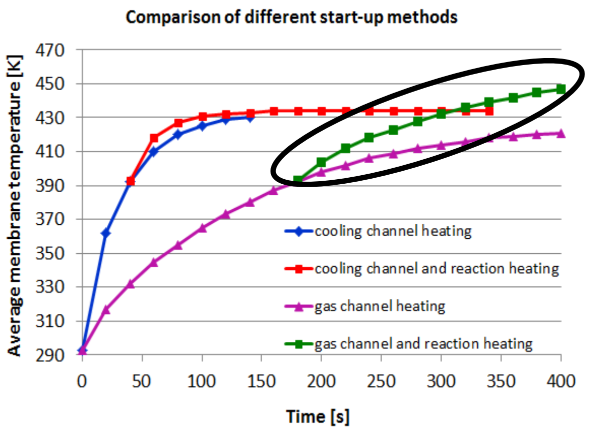
Result comparison of start-up methods



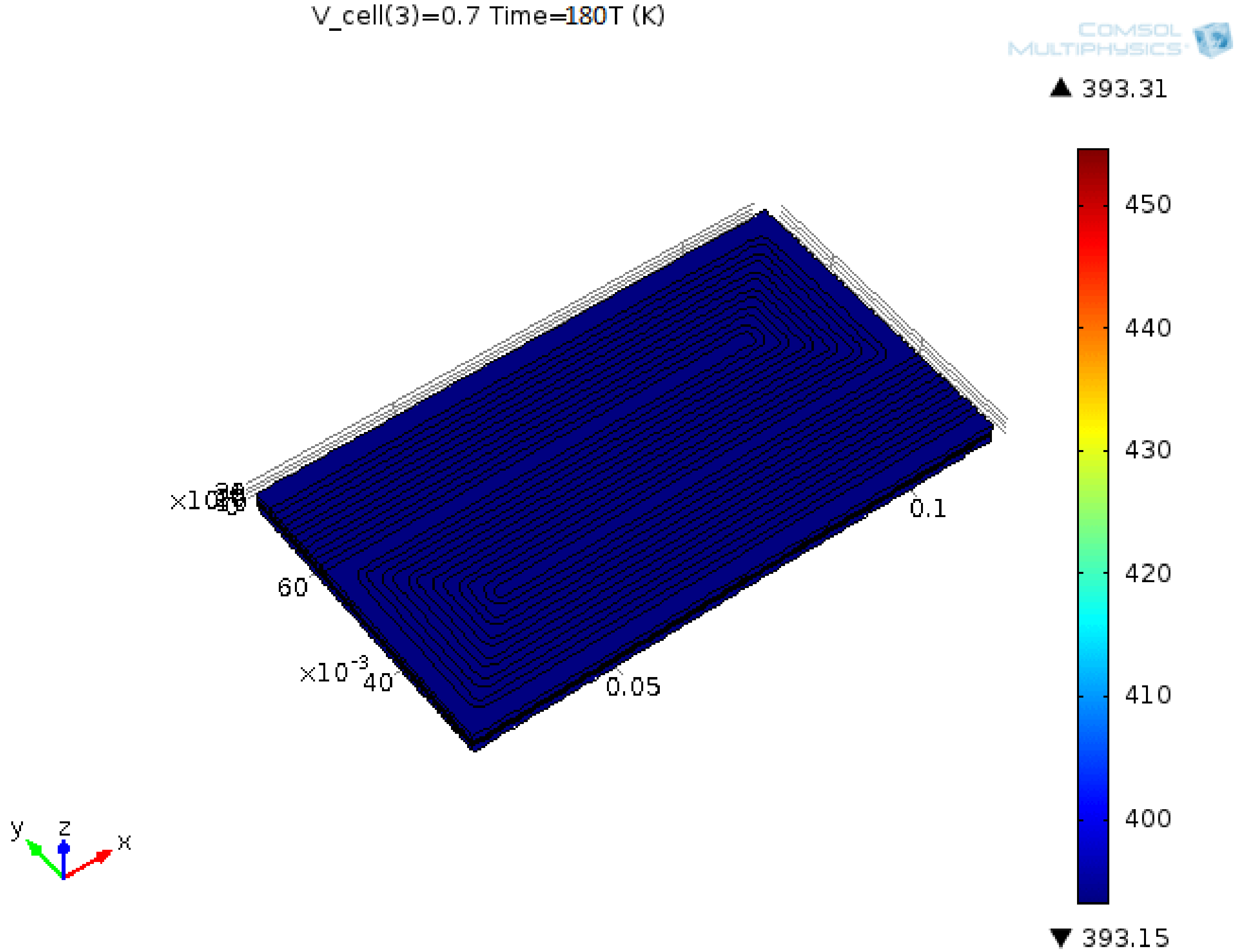
Start chemical reaction when average membrane temperature reaches 120 °C

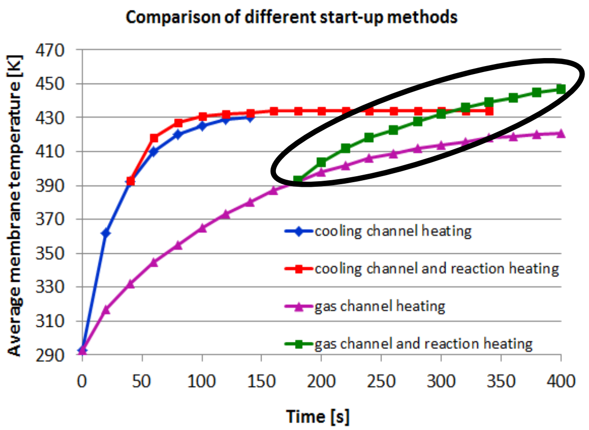
Start-up only by reaction from 120 °C from 180 s





Start-up only by reaction from 120 °C from 180 s





Summary

- Comsol model for fluid dynamic, chemical engineering and thermal dynamic

↓

- Start-up methods for HTPEM fuel cell
  - Cooling channel heating much faster than gas channel heating
  - Reaction heating speeds up heating process
  - Combining reaction with cooling channel heating stabilizes the cell temperature

↓

- The combination of reaction and cooling channel heating is the optimal start-up process for this cell configuration

Acknowledgement

This work has been done in the framework of the research project “1 kWel fuel processing system integrated with an advanced high temperature fuel cell stack for UPS application” funded by the German Federal Ministry for Education and Research.

Modeling of HTPEM Fuel Cell Start-Up Process by Using Comsol Multiphysics

Comsol Conference Europe 2012

23.10.2012

Yu Wang, Julia Kowal, Dirk Uwe Sauer

Electrochemical Energy Conversion and Storage Systems Group, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University, Germany

batteries@isea.rwth-aachen.de