Porosity as a contributor to solutions for sustainable production

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Outline

- Introduction
- Ceramic membranes
- Porous scaffolds for bone regeneration
- Ceramic foams as filter or as catalytic support
- Conclusion

Introduction

Sustainable manufacturing must be:

- more efficient and less energy consuming
- non or less polluting
- resource efficient
- improved components

The use of porous materials can be a solution

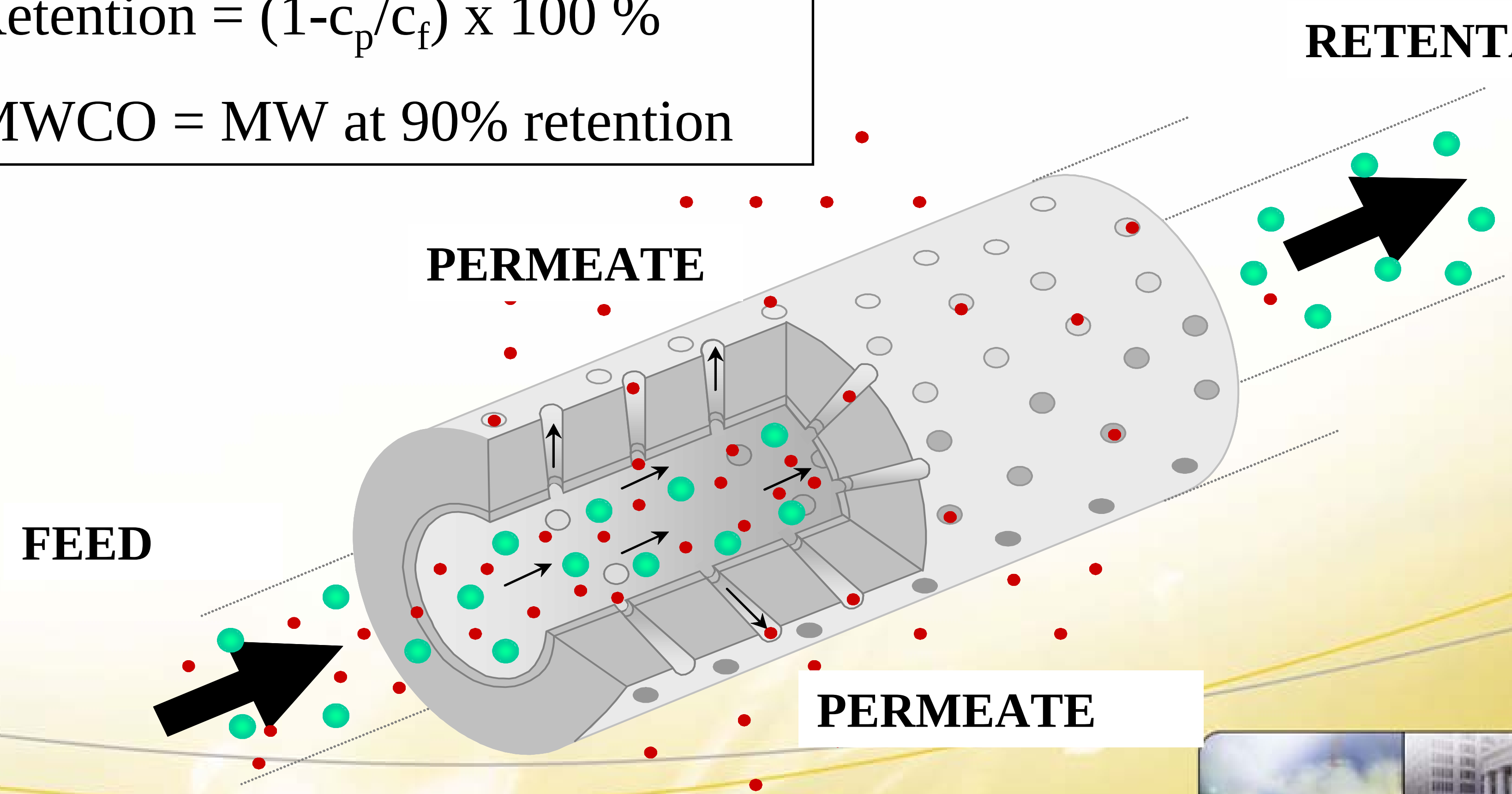
- ceramic membranes
- porous orthopedic implants
- ceramic foams as filter or catalytic support

Membrane filtration

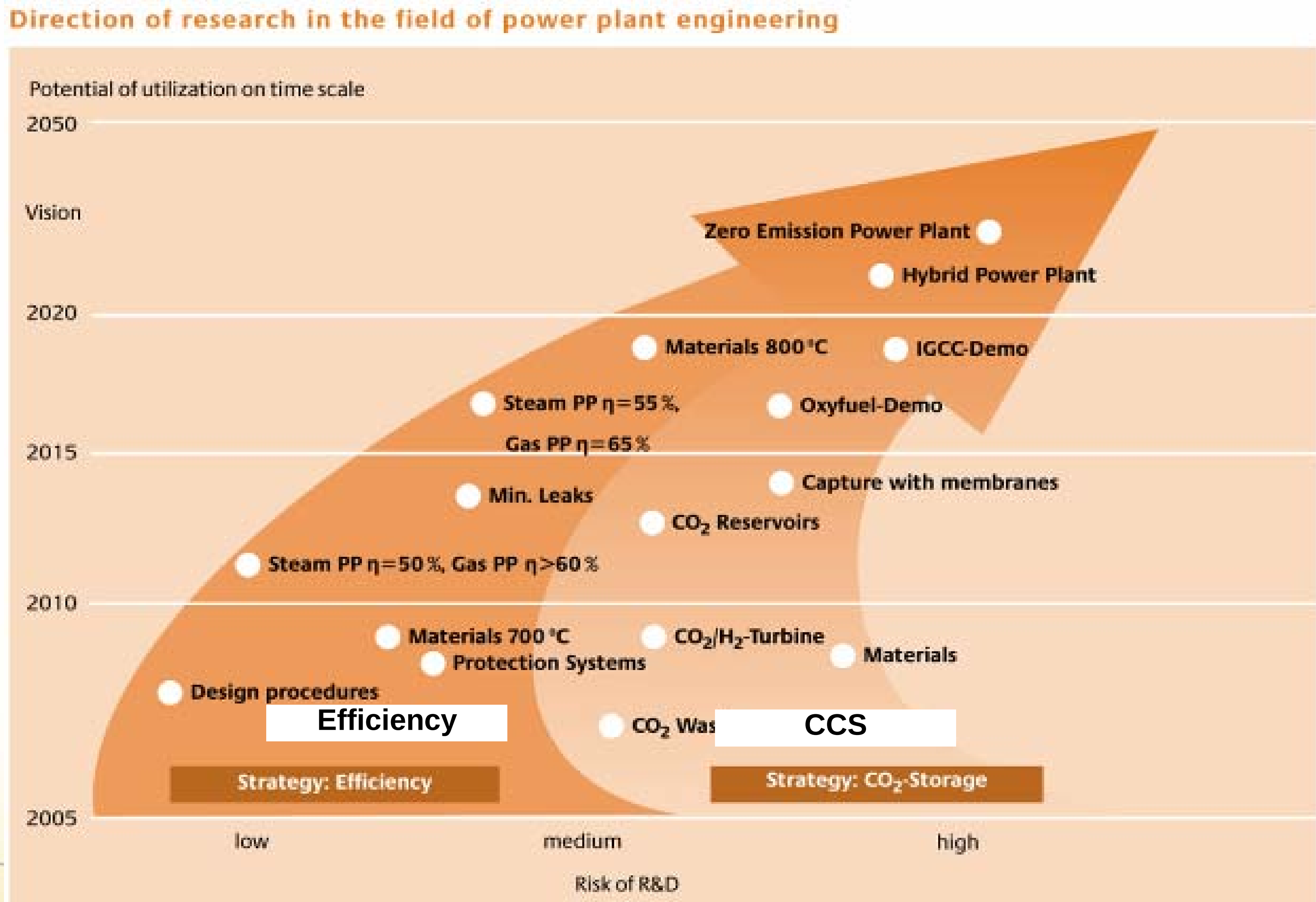
Permeability (l/hm²bar)

Retention = $(1 - c_p/c_f) \times 100\ \%$

MWCO = MW at 90% retention

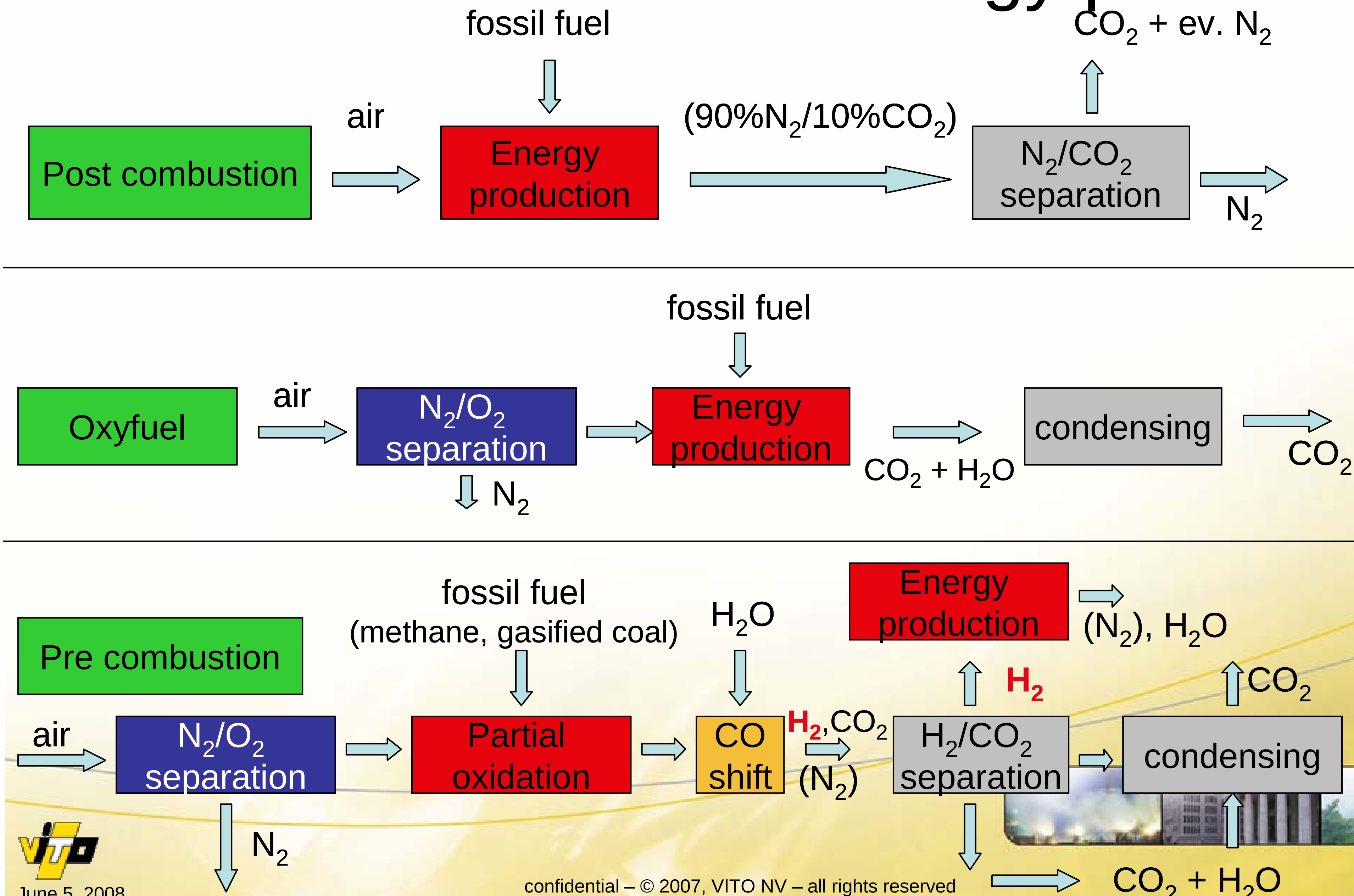


Approaches to reduction of CO_2 emission



Data source : German COORETEC initiative

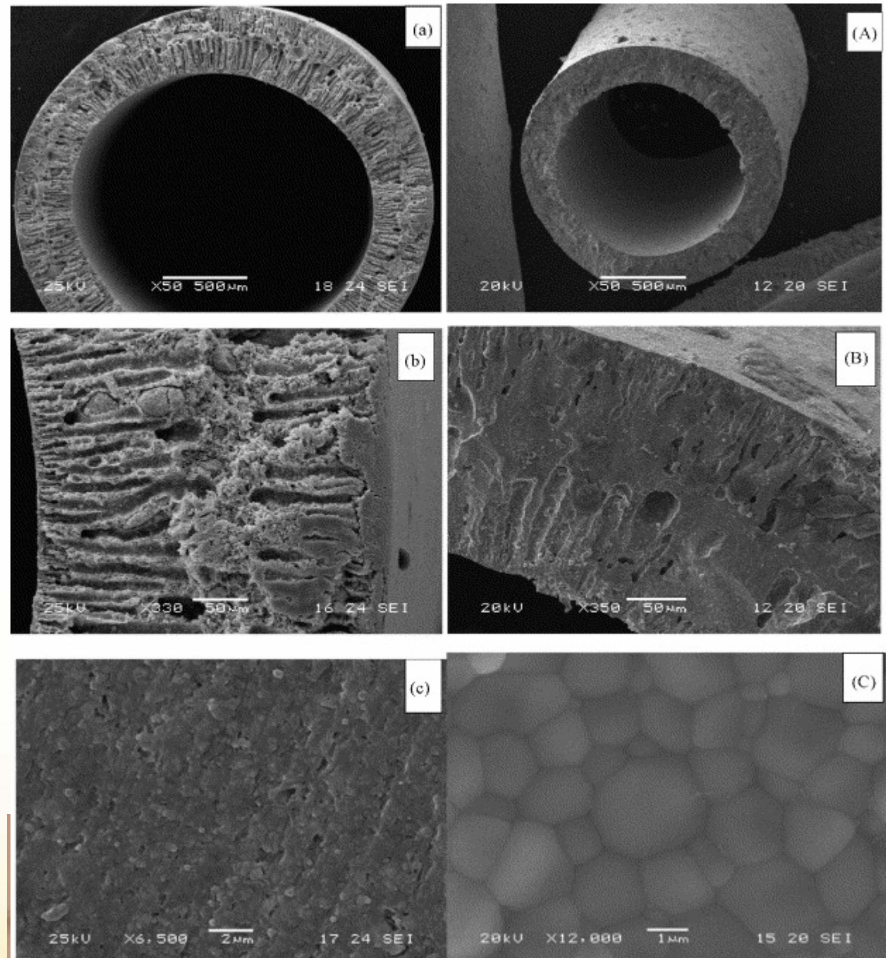
Routes for sustainable energy production



Ceramic hollow fibers

- Dens ceramic (proton and oxygen conductors) membranes, hollow fibers
- High surface area to volume ratio of hollow fibers enhance membrane fluxes
- Spinning with phase inversion,
- Bending strength upto 80 MPa

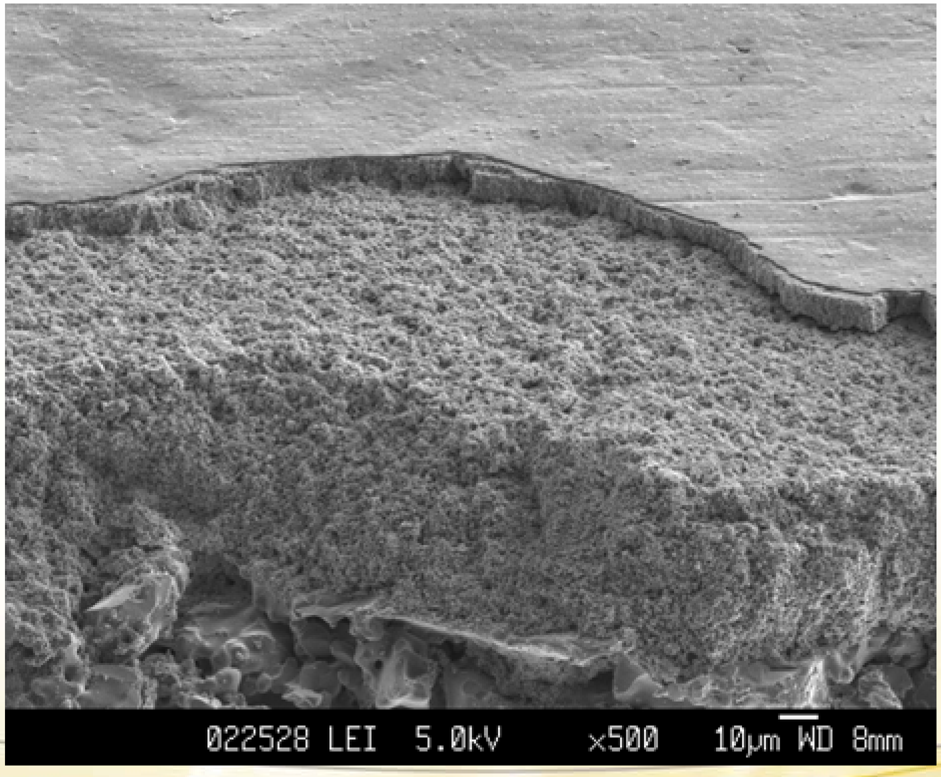
VITO participation in ‘MEM-BRAIN’-project (FZJ, Helmholtz-institutes)



J. Luyten, A. Buekenhoudt, et al., Preparation of LaSrCoFeO3-x membranes, Ceramic Trans., vol 109.

Ceramic NF membranes

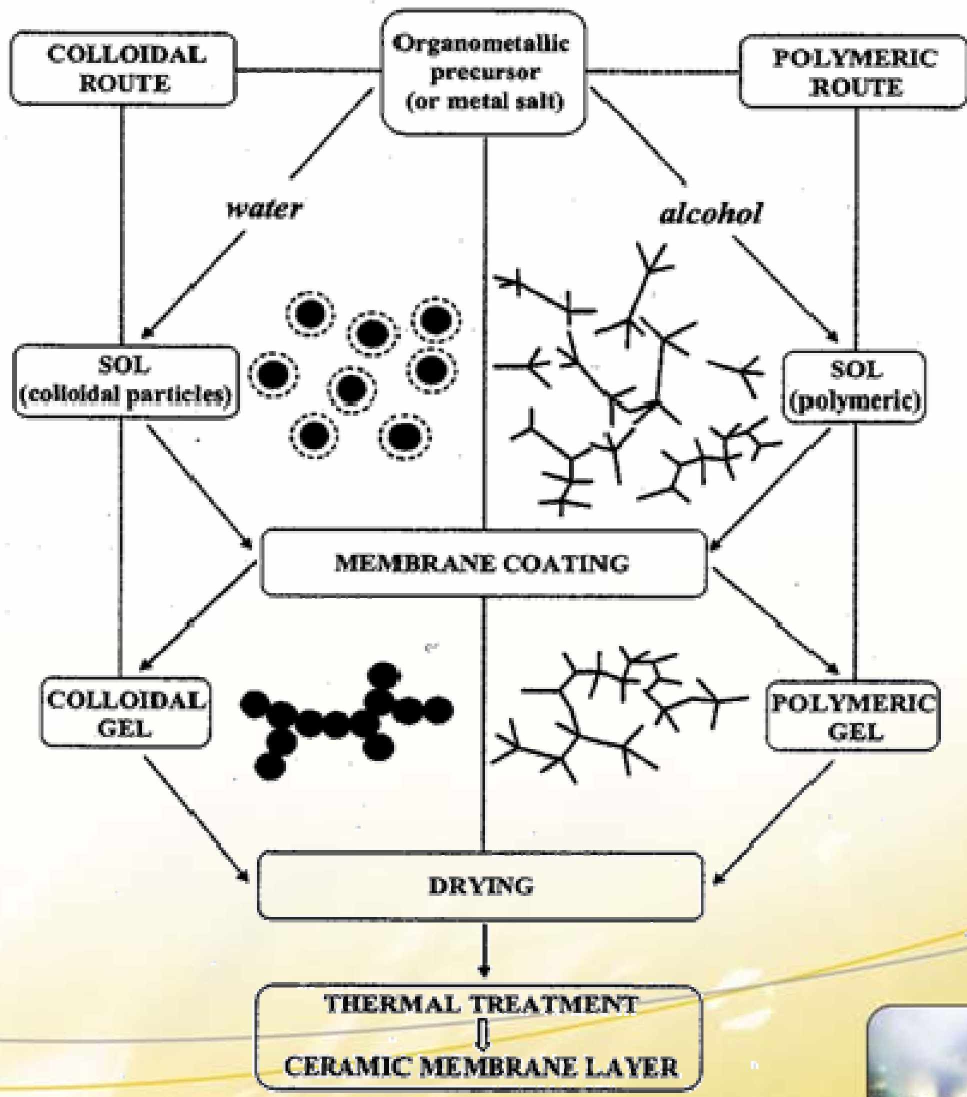
High flux + retention : multilayer structure



1 or 2 toplayers (NF)
2 interlayers (UF)

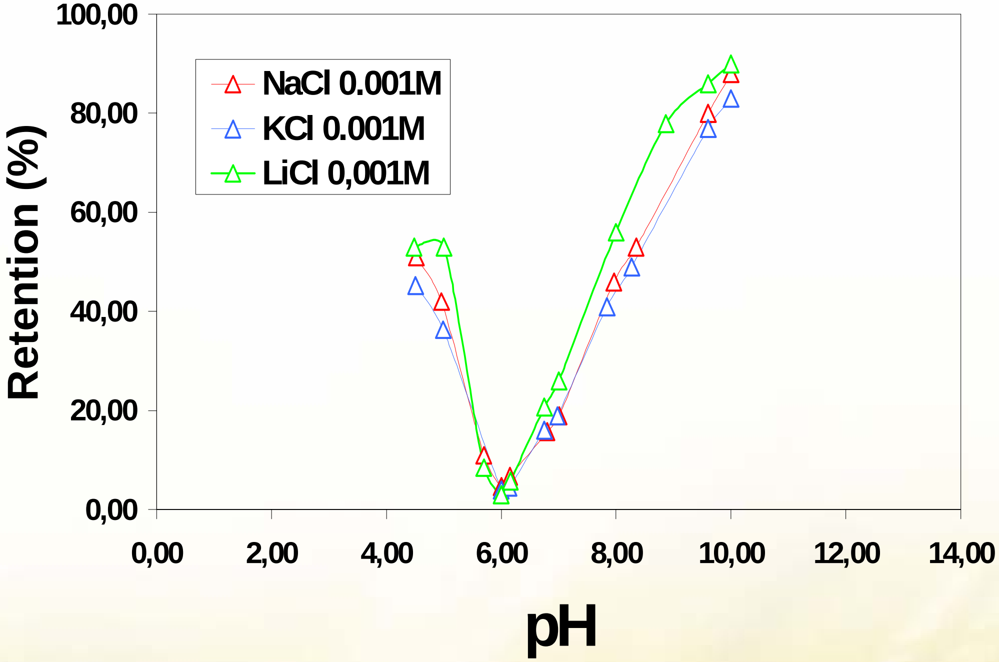
support

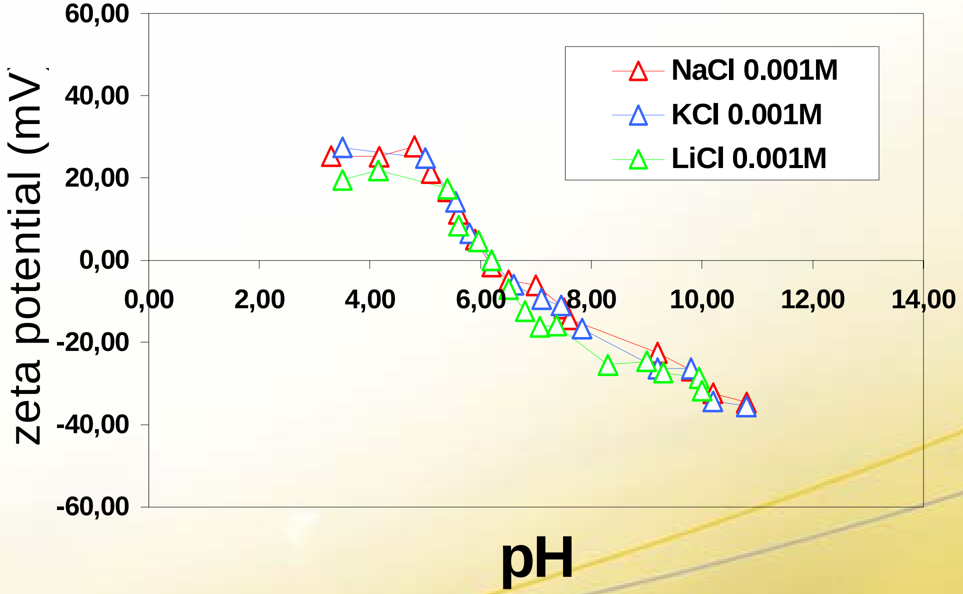
Sol-gel coating (colloidal, polymeric)



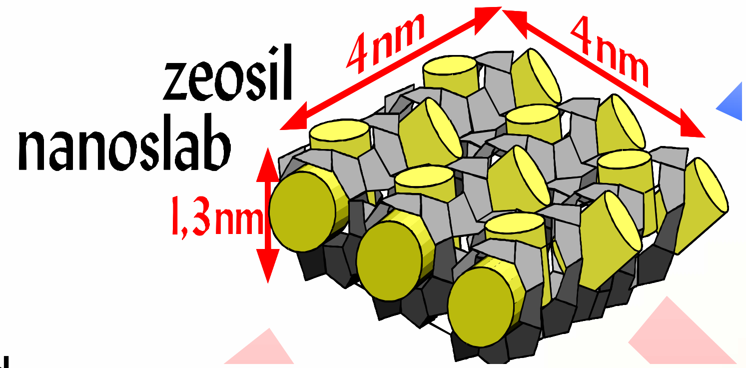
Separation performance in water

Salt retention : monovalent salts on TiO_2 NF membrane



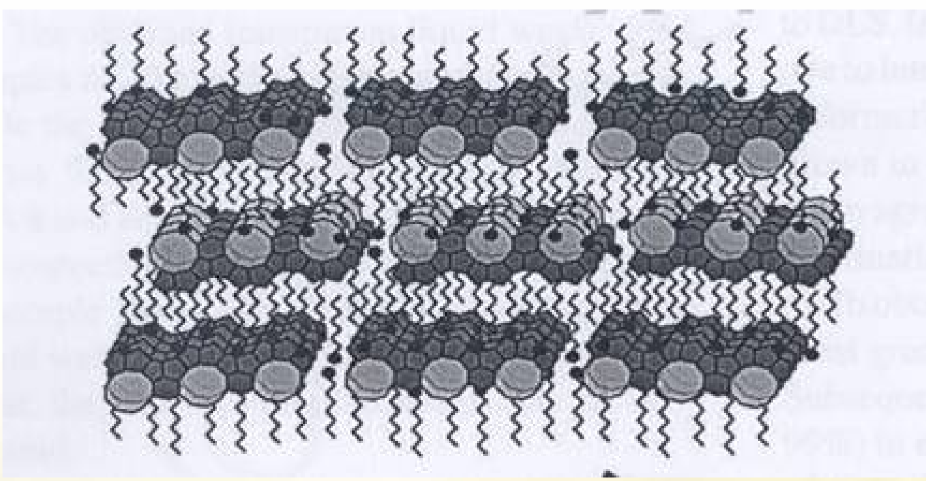


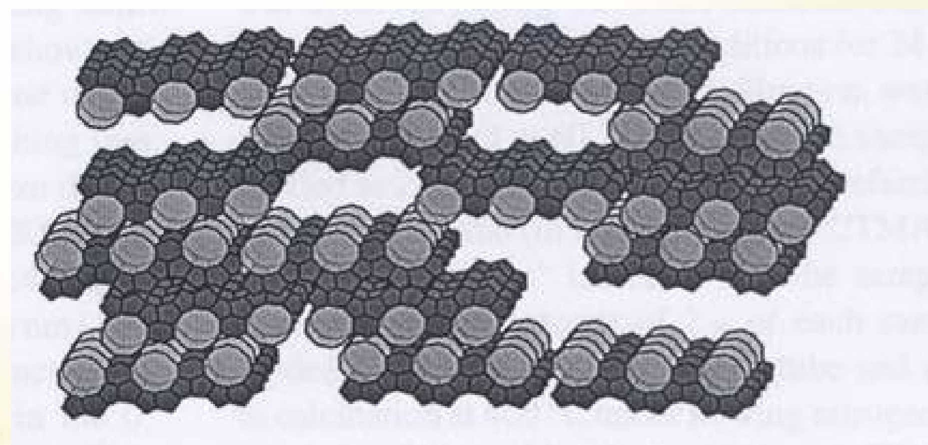
Zeogrid powder



Recently discovered know-how [X] :

- Nanoblocks can be stacked in an ordered way with the use of appropriate surfactants
- Leads to micrometer large grains called zeogrid
- Zeogrid calcined has dual porosity : micropores(0.5nm)+ interblock voids

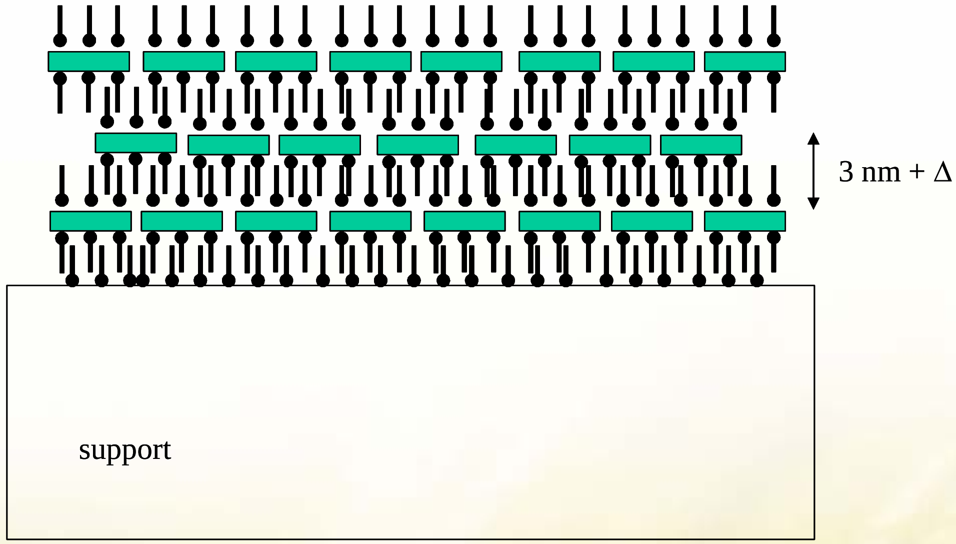


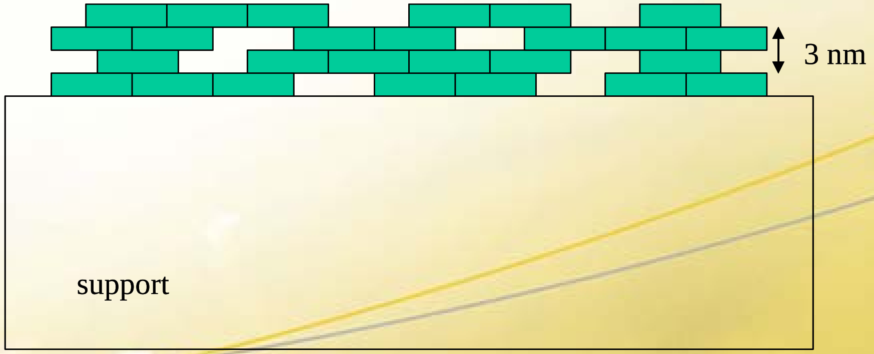


[X] Kremer at al., Adv. Funct. Mater., 12, 286, 2002

A new generation of zeolite membranes

- Zeogrid on support : dipping in solution of nanoblocks + surfactants
- thin membranes < 100 nm : high flux, crack free, high selectivity
- simpler production than hydrothermal synthesis





Zeogrid layer on porous support

Supports :

flat and tubular

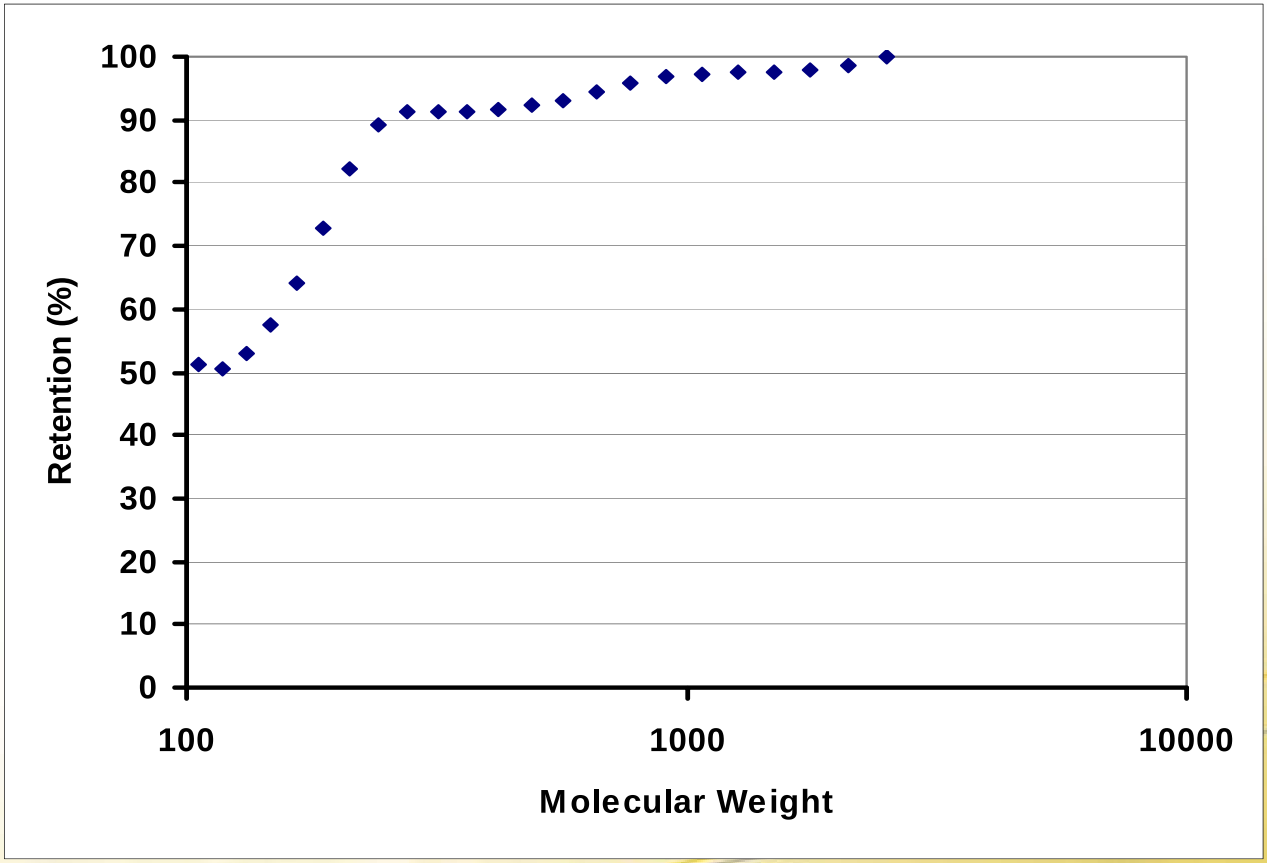
α-Al_2O_3 (100 nm)

and α-Al2O3/TiO_2

(50 nm) + TiO_2 (3nm)

Zeogrid coatings :

with surfactant



Ceramic Foams

- **Ceramic foams are a cellular material with a broad field of applications:**
  filters for molten metal, dust and soot filters, scaffolds for bone replacement, high temperature isolation,…

- **Application performance is strongly related to cell size, window opening and other structural parameters**

- **Objective is to produce ceramic foams with sufficient strength and controlled micro-macro structure.**

- **We produced ceramic foams by:**
  -A reaction bonded PU replica technique
  -Biogelcasting of foams
  -Hollow beads method
  -Robocasting

Manufacturing routes

1. PU Replica technique

metallic aqueous suspension

↓

Infiltration/coating polymeric foam

↓

Removing excess

2. Bio gel casting

metallic suspension + foaming agent + gelling agents

↓

Foaming of mixture

↓

Moulding

↓

Gelation

3. 3D fiber deposition

Viscous metallic paste

↓

Extrude through thin nozzle

↓

Computer controlled deposition of fibers

↓

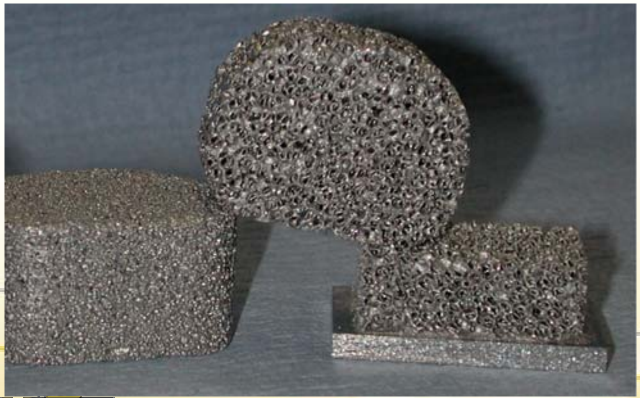
Drying, calcination

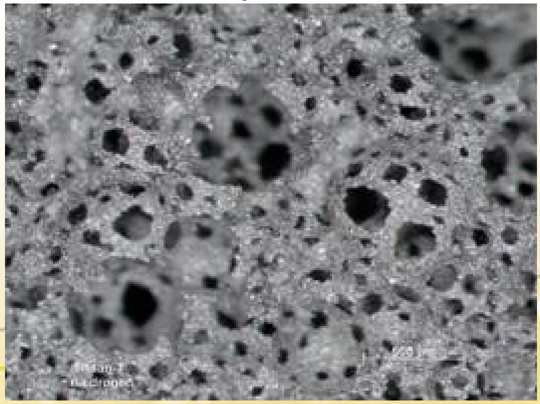
↓

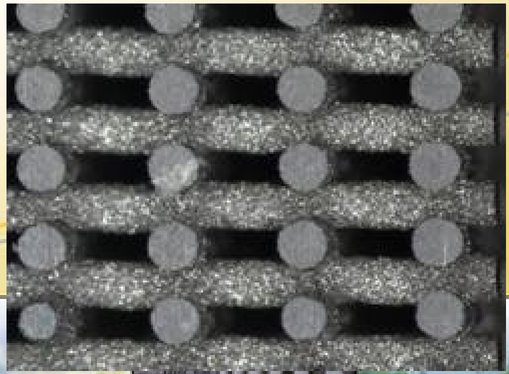
Sintering

↓

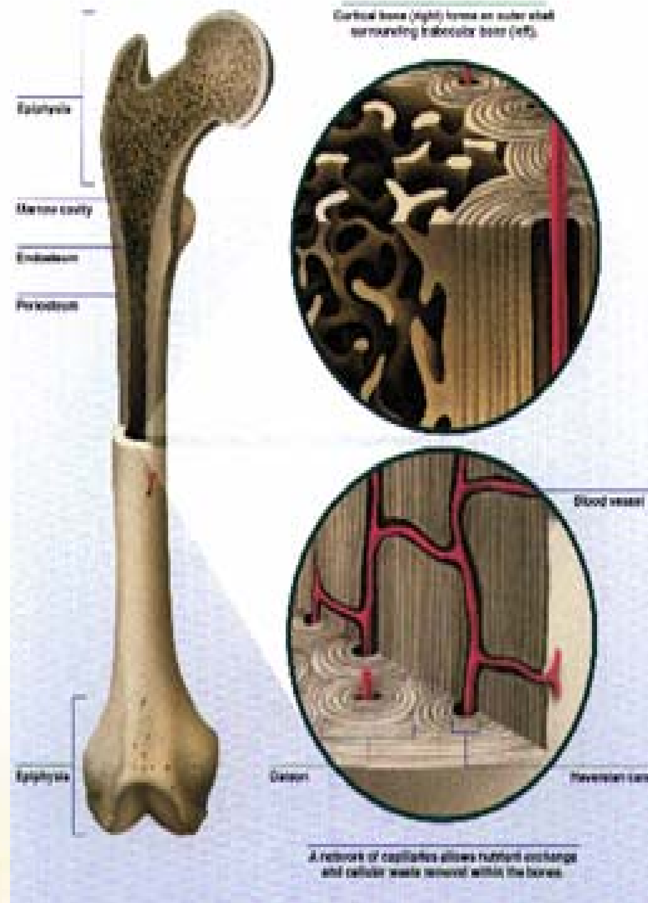
Porous Metal Structures



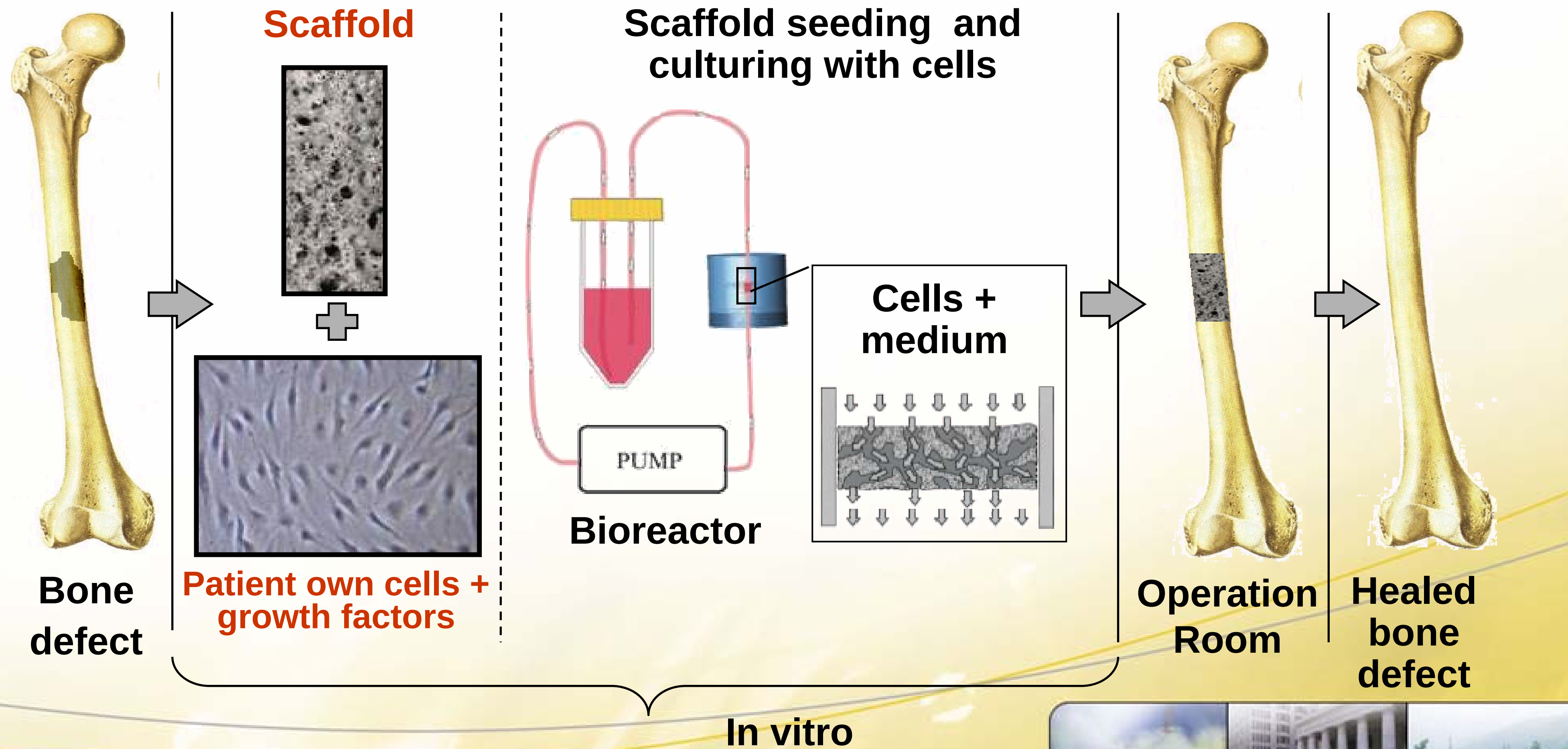




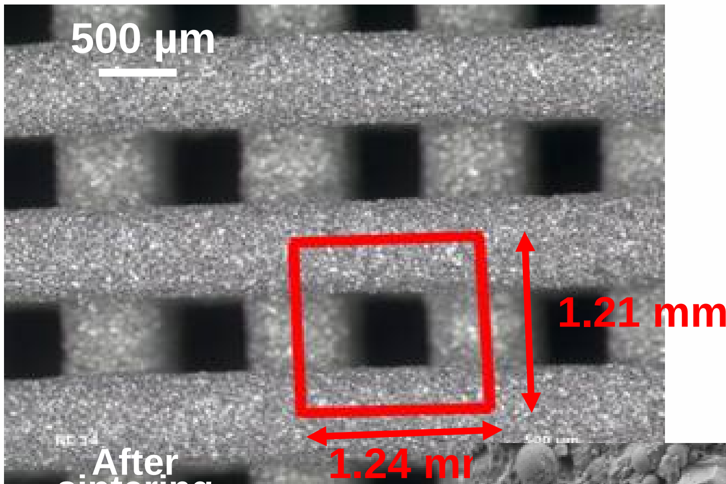
Quality of Life of elder people

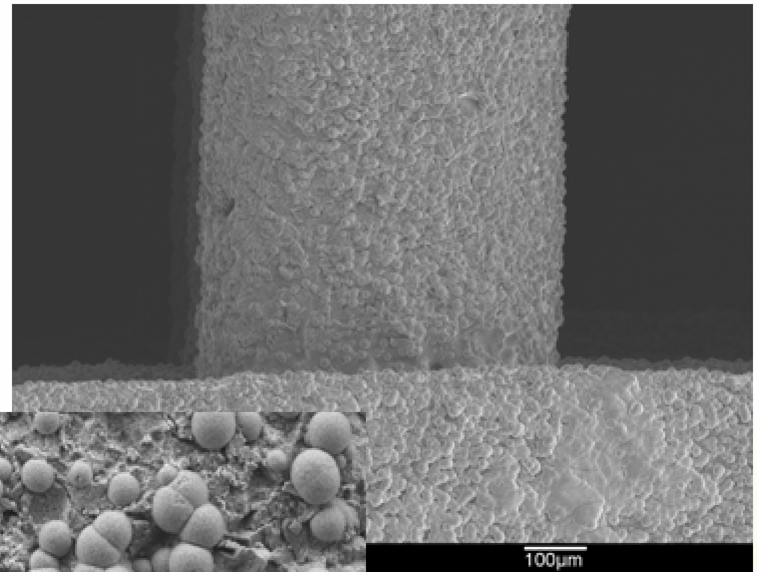


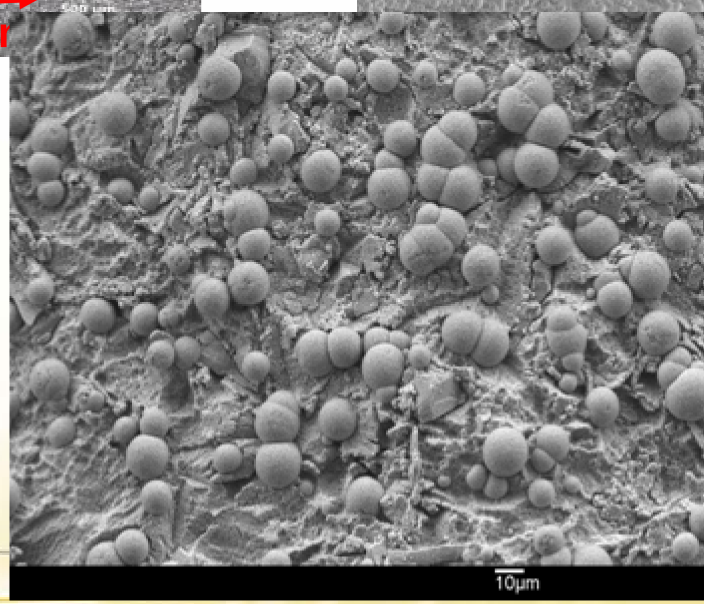
Tissue Engineering for Bone generation



Orthopedic Implants
Ti-foams + biomimetic coating

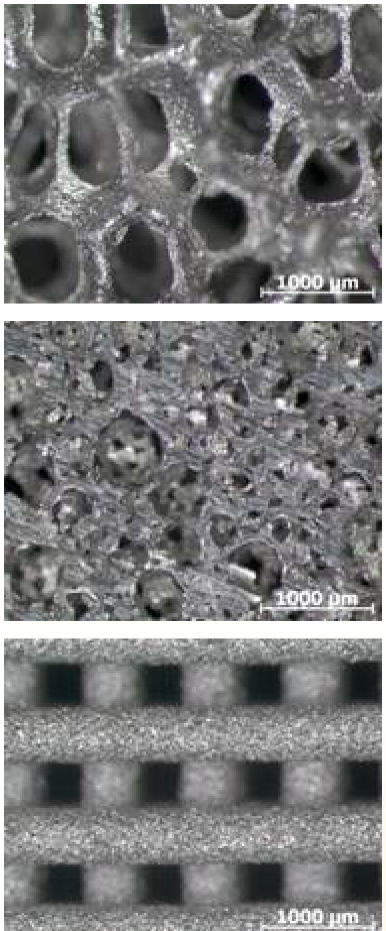






Drug delivery system

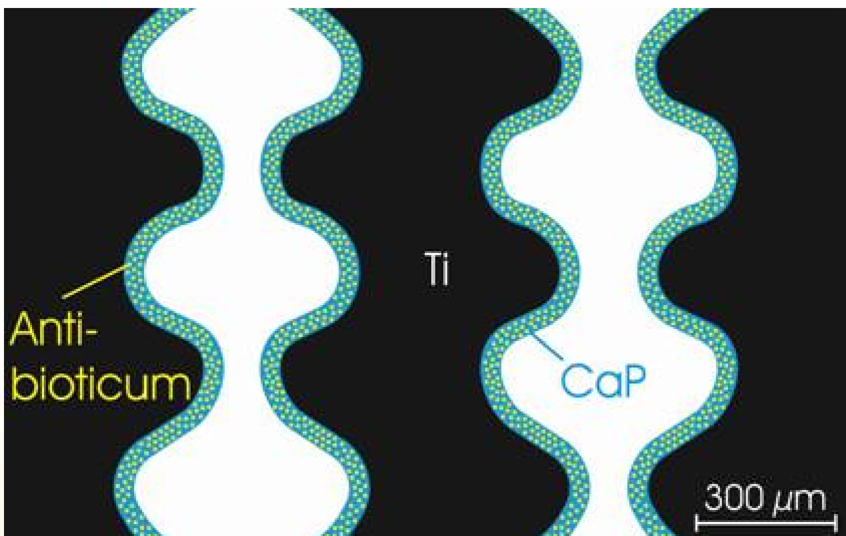
Porous Ti-structures



Local drug delivery system

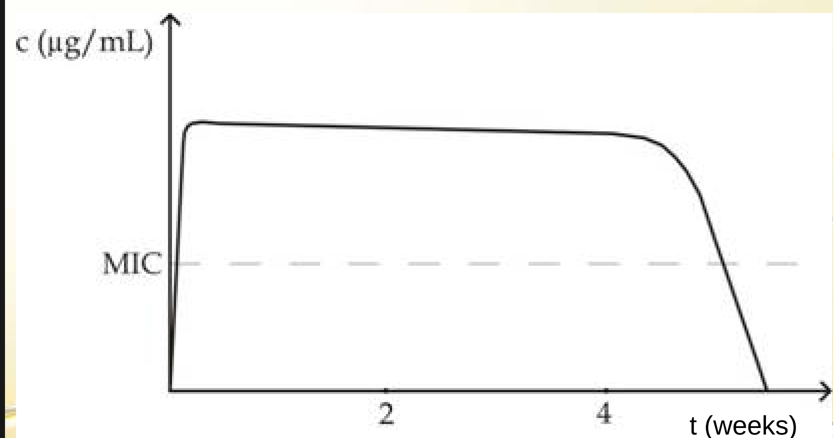
CaP coating

- osteoinductive
- drug delivery matrix



optimal release profile

- initial burst release
- therapeutic concentrations from a few weeks till some months
- sharp release fall at the end



CaP: calciumfosfaat

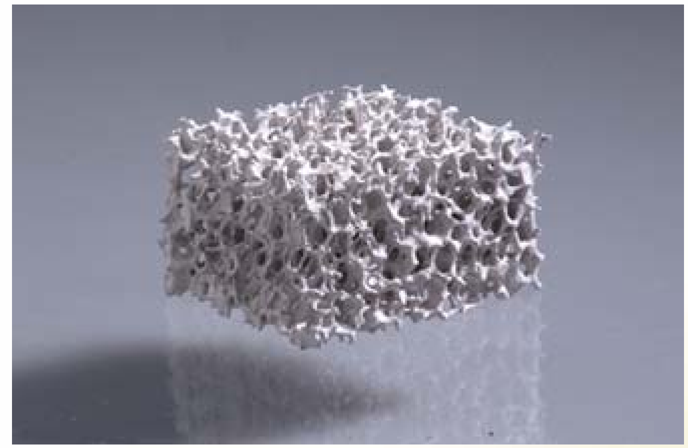
Filter for Molten Metal

- **EU project Al recycling project aiming to remove intermetallic materials from the molten melt**

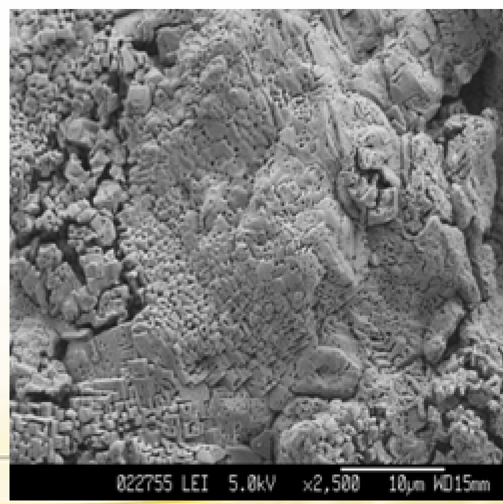
  - RB Mullite replica technique,

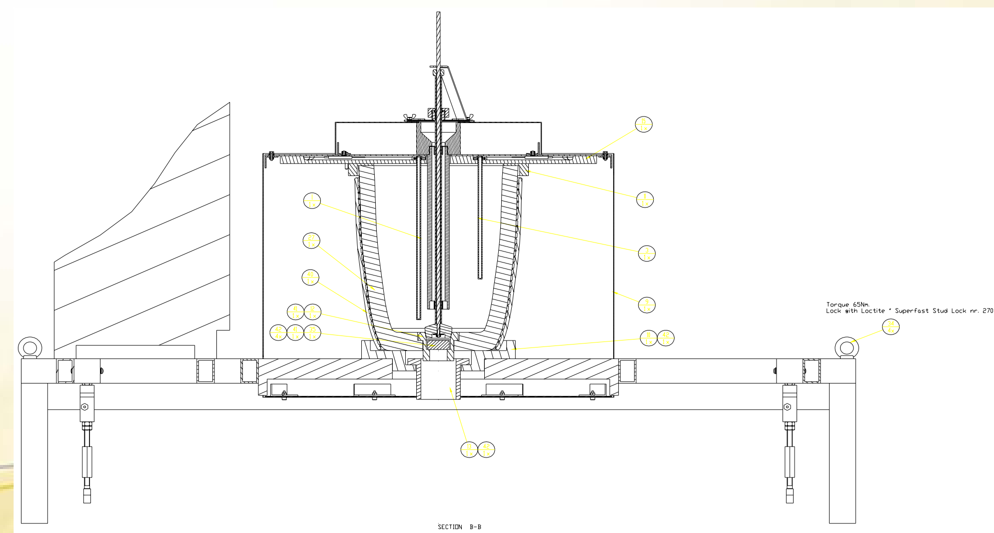
  - with a gradient in cell size

  - coated with a salt



- Filter tests

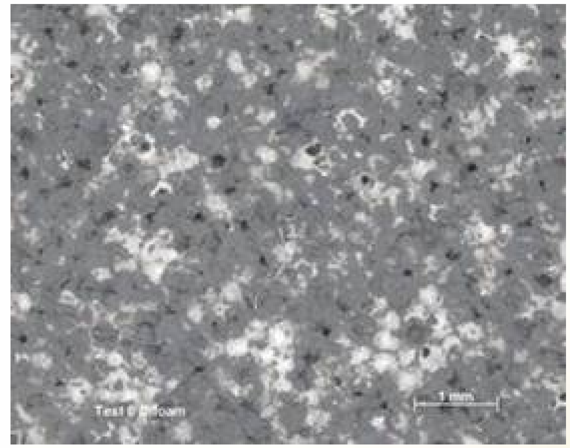




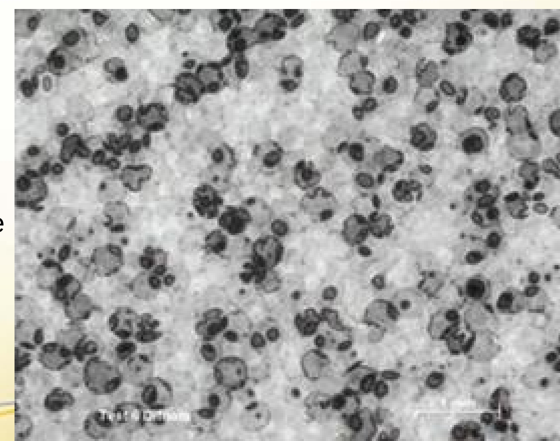
Soot Filter for diesel cars

- 90% removal of particles with low pressure increase.
- Replica technique on different Pu cell sizes
- Improve strength by using RB-processing
- Can be washcoated

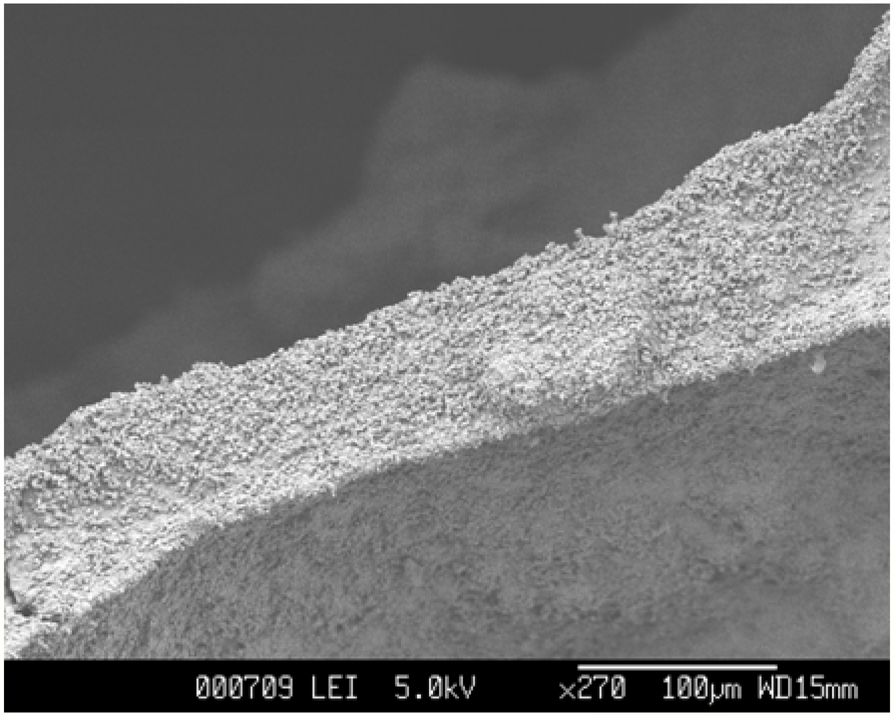
Inlet side

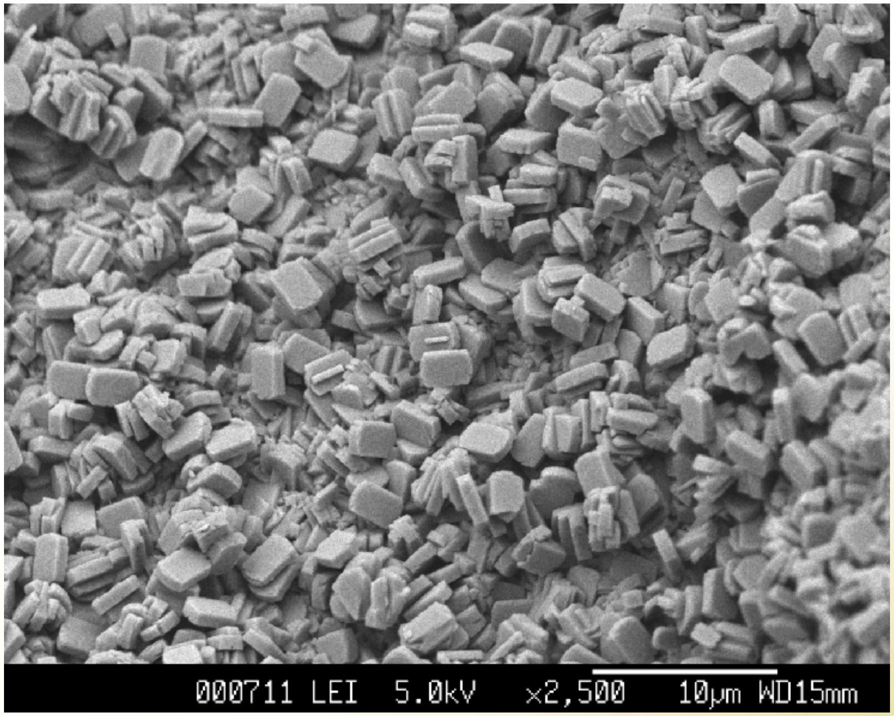


Outlet side



Zeolites on a Catalytic ceramic foam





Conclusions

- **Sustainable production is a need**
- **We demonstrate that different kind of porous materials can contribute to such process improvement**
- **Special attention was given to the use of ceramic membranes and to different application with ceramic and metallic foams**

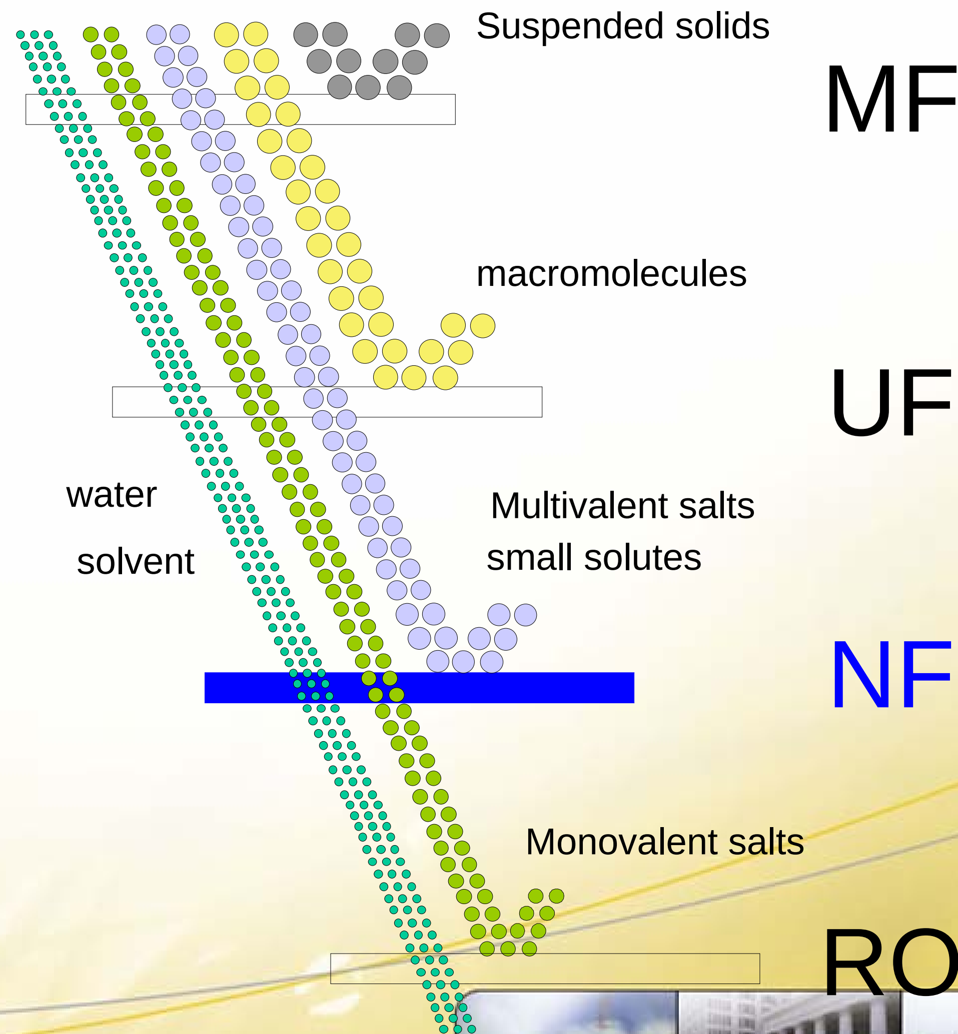
Different pores : different filtration proces

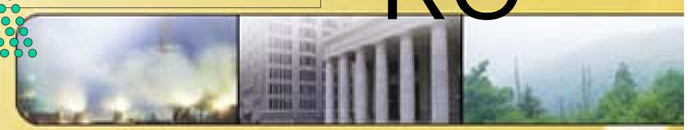
MF
0.1 - 3 bar
0.1 - 20 µm

UF
2 - 10 bar
2 nm - 0.1 µm

NF
5 - 30 bar
≈ 1 nm

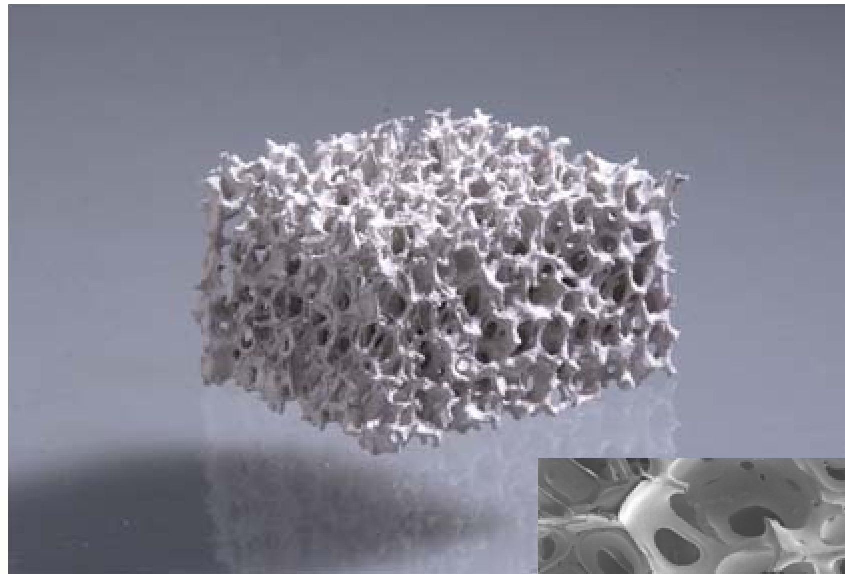
RO
10 - 100 bar
0.1 - 1 nm (dens)

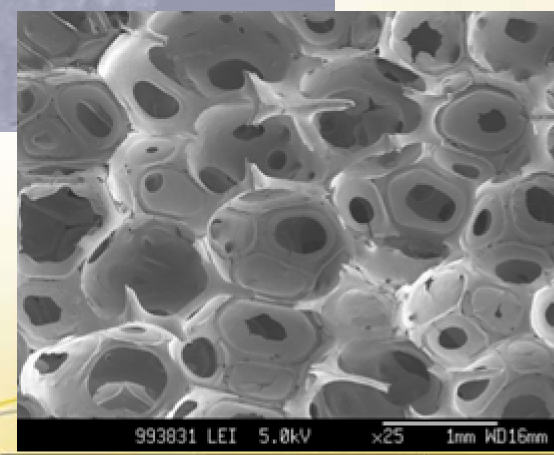




Reaction Bonded Modified Replica Technique

- Preparation of the metal/metaloxide mixture
- Preparation of an aqueous slurry (no gas evolution, rheology)
- Coating of the PU-sponge, squeezing and drying
- Calcination and oxidation
- Sintering





Gel casting

Ceramic suspension → **Foaming agent** → **Hydrocolloid**

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Mixing / foaming

↓

Moulding

↓

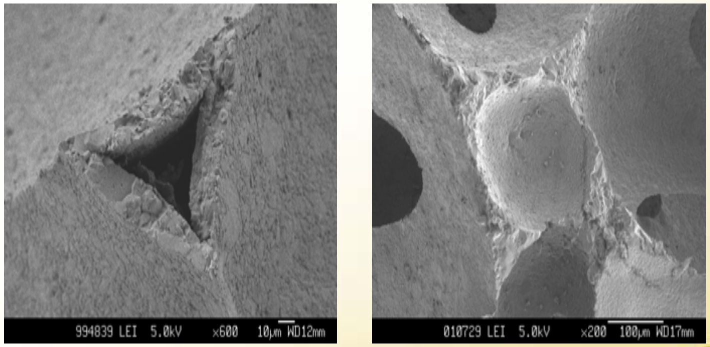
Gelation

↓

Thermal treatments

↓

Ceramic foam structure

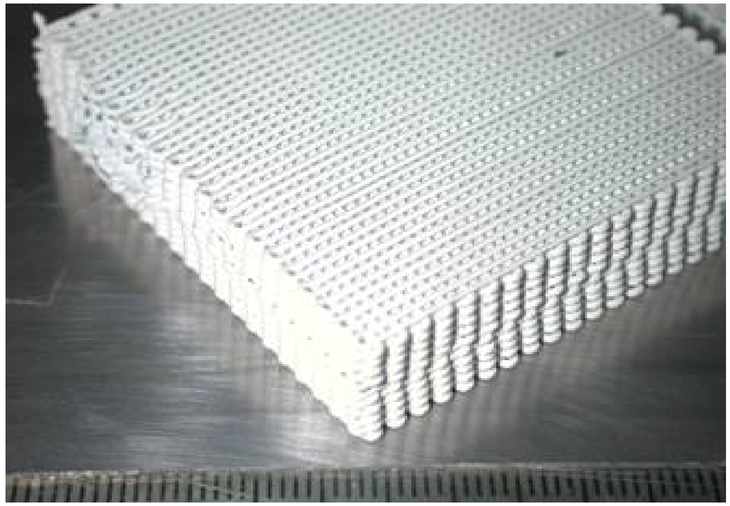


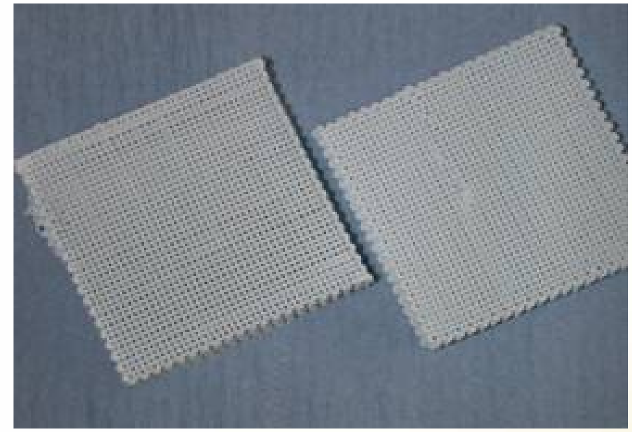
1a) 1b)

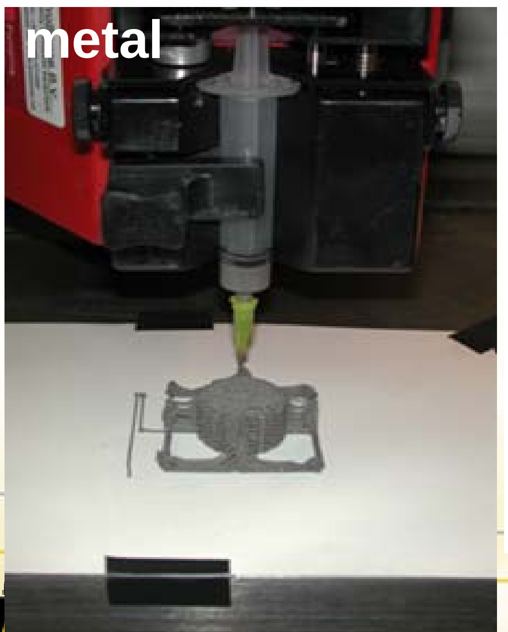
Hollow beads method

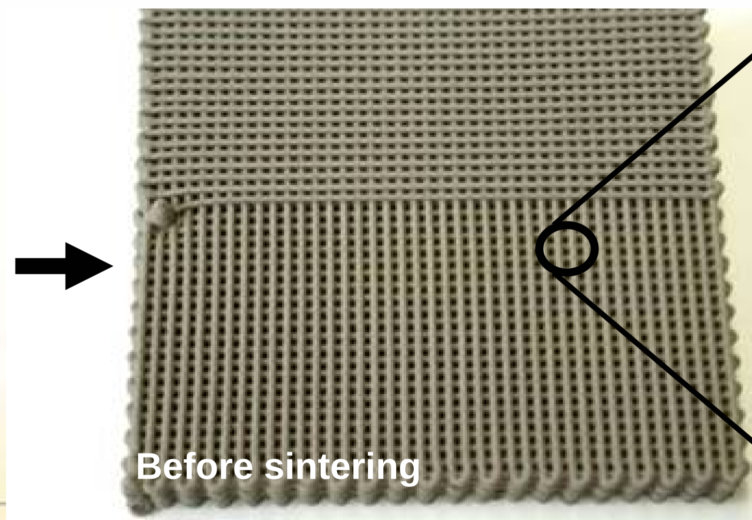
- **Preparation of the slurry**
- **Coating of the sacrificial cores (peas, seeds, styrofoam granules,…)**
- **Packing of the cores**
- **Second coating**
- **Thermal treatments (drying, calcining, sintering)**

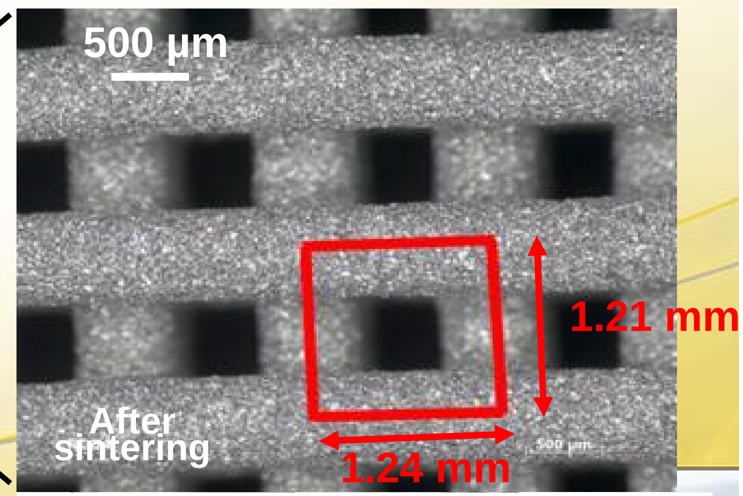
3DFD











~40-50 %TD

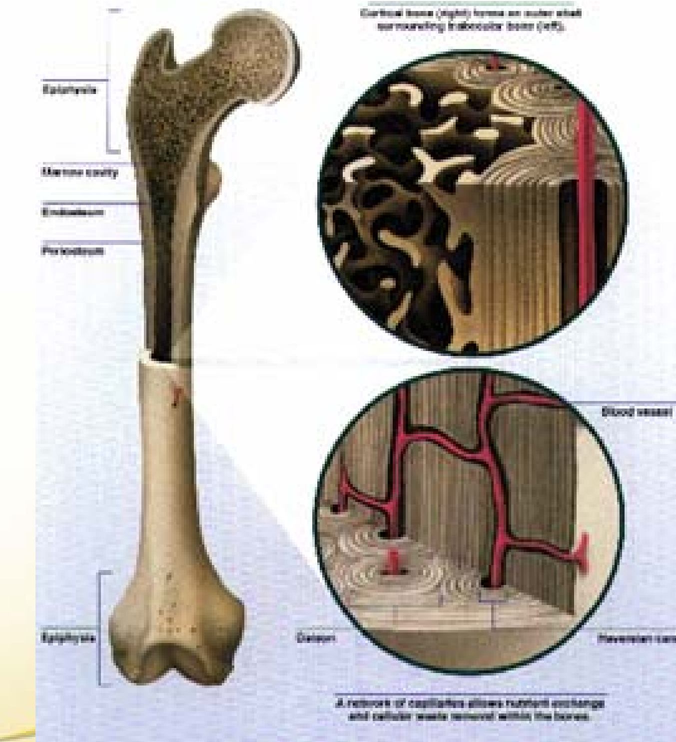
Pore sizes ~500 x 500 µm

Bone scaffold requirements

- Biocompatibility: bio-inert or bio-active
  - Bio-inert metals: Ti-6Al-4V, Ti, SS, Ta
  - Bioresorbable ceramics: hydroxyapatite, α- or β-tri calcium phosphate .
  - Biodegradable polymers: PGA, PLA, PGLA

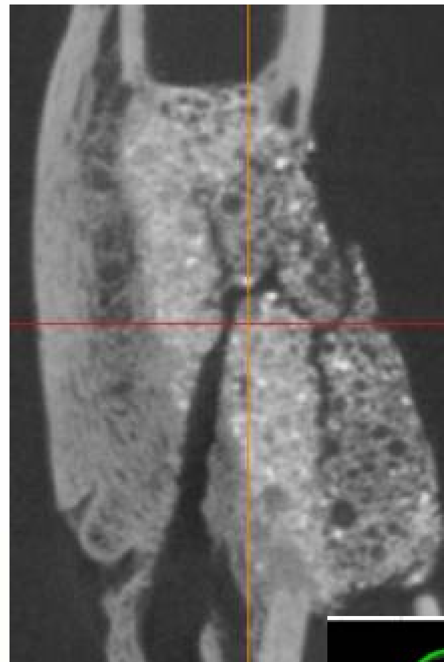
- Structural parameters:
  - High porosity
  - Open porosity :
    - Allowing osteoprogenitor cell seeding
    - cell attachment/cell migration
    - Mass transport cell nutrition
  - Interconnectivity
  - Specific surface area

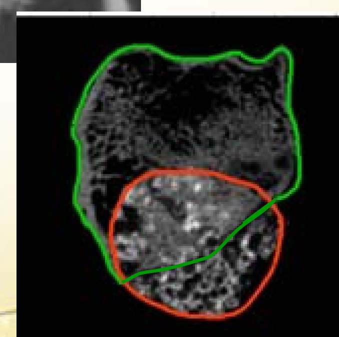
- Adequate mechanical behavior



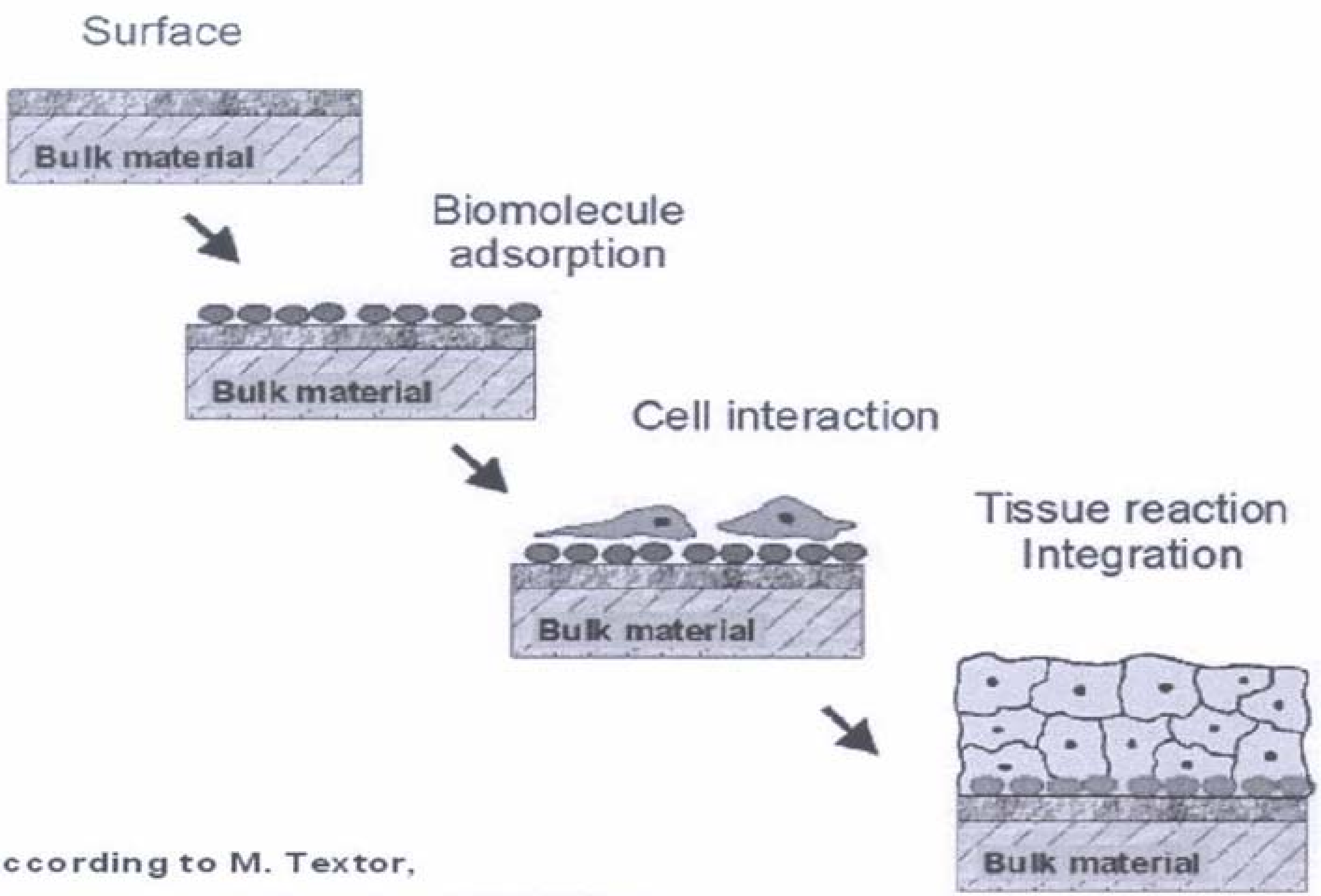
In vivo behavior

- Nude mice model
  - Ectopic implantation
  - Osteoinduction?
- Rabbit
  - Tibia – large defect
  - Scaffold h=20mm; ø=6mm





Steps to tissue integration



According to M. Textor,
Department of Materials, ETH Zürich