New materials from the digital material laboratory

Andreas Wiegmann

CEO, Math2Market GmbH

Hannover Messe, April 26th, 2017

GeoDict

MATH 2 MARKET

Math2Market GmbH and its GeoDict software
Some background information

- Math2Market creates & markets software to analyze/design porous & composite materials based on the material's geometric inhomogeneity
- M2Ms software is called GeoDict, the Digital Material Laboratory
- GeoDict works on µCT-based, FIB-SEM-based and intrinsic models - in all cases, the computer representation consists of 3-D images
- M2M was spun off in 2011 from Fraunhofer Institute for Industrial Mathematics
- M2M is based in Kaiserslautern, Germany, and privately owned
- M2M has more than 100 clients from around the world

Mission & Vision

- Our vision is to help our clients profitably engineer better materials and processes through digital solutions

- Our mission is to simplify material engineering and to create new standards using digital material models

Math2Market GmbH
Location and Contact

Offices and visitor address:

Stiftsplatz 5
67655 Kaiserslautern
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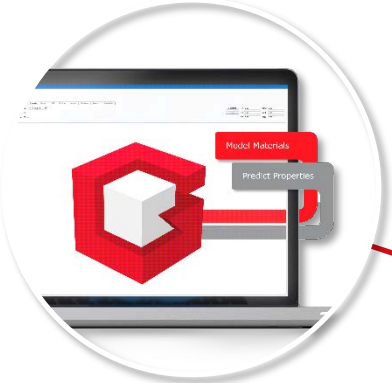
www.geodict.com

Our focus is on the client



Software

Client

User Guide

Support & Training

Consulting & Projects

An earlier version of the GeoDict logo was created in 2001 at ITWM.
Since 2012 GeoDict is a registered trademark of Math2Market GmbH.

We not only develop the GeoDict Software but also:

- Do Projects with you to fit our GeoDict to your needs
- Offer Training sessions to improve your productivity with GeoDict
- Support you to reach your goals with GeoDict

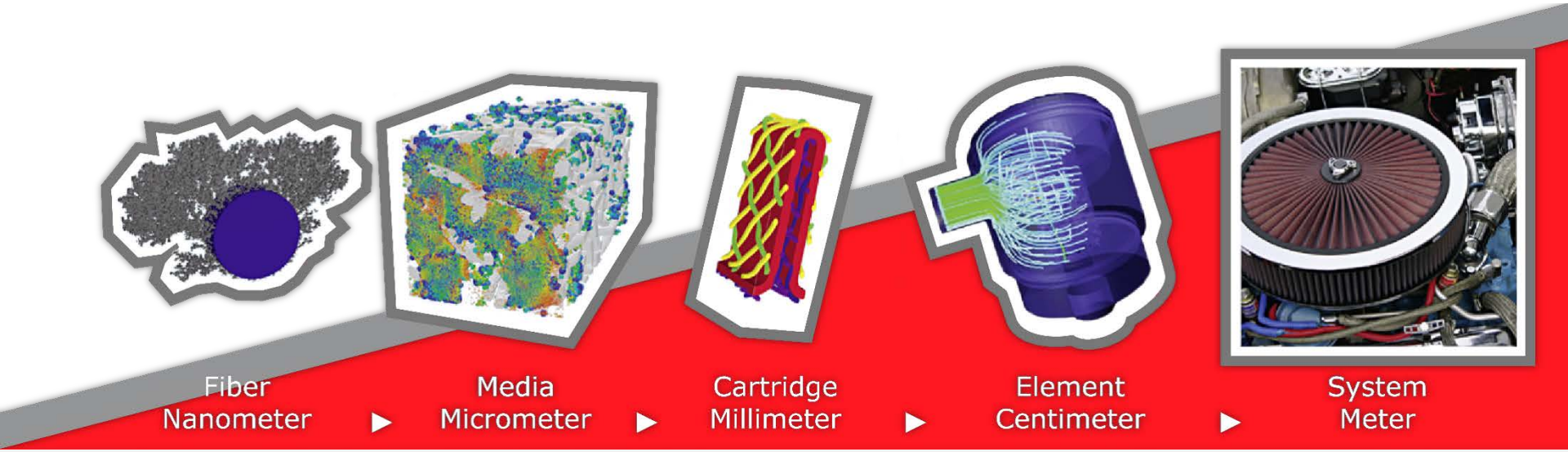
Math2Market GmbH
Cooperation with Fraunhofer ITWM

”If our research and technology was turned into commercial software at all, it could take 10 or more years to do so.
With M2M, the transfer can be achieved in as little as 2-3 years!“

Dr. Konrad Steiner

Fraunhofer ITWM

Head of department “Flow and Material Simulation”



Startup Experience

1998 BMBF funded two-phase flow simulations in fibrous filters

1999 W. as user of fiber generator and flow solver

2000 First visualizations of materials and flow processes

2001 Fraunhofer Prize “Virtual Material Design”

2001 Invention of product name “**GeoDict**”, Logo by ITWM PR

2001 FhG Workshop identified filtration & mechanical properties simulation as major industrial needs

2001 Stiftung Innovation Rheinland Pfalz funded particle tracking

2003 Addition of DDFEM Mechanics Solver

2003 First Filtech presentation and exhibit

2003 First GeoDict workshop, 4 sales – all clients of M2M today!

Startup Experience

2004	First filtration clients, MANN+HUMMEL and BOSCH
2005	Becker joined W.'s group
2005	First fuel cell projects, client requested scripting
2006	BMBF funded DPF simulation project with BOSCH
2007	First Pore Size Analysis at Filtech
2008	W. attended Fraunhofer Venture seminar
	Glatt joins W.'s group
	Exhibit at World Filtration Congress in Leipzig, meet GKD
2009	Began contract work for spin-off
2011	Wiegmann, Becker & Glatt founded M2M
	Last minute name changed from TGC (The GeoDict Company)
	Japanese distributor SCSK scouted ITWM

Difficulties associated with new high-tech ventures spun off from universities and research institutes

- Novelty of the venture and inexperience of the entrepreneur, give rise to a “liability of newness”
- Evolution from an initial idea in a non-commercial environment to becoming established as a competitive revenue-generating firm.
- Conflicting objectives of key stakeholders such as the university / institute, the academic entrepreneur, the venture’s management team and suppliers of finance

Difficulties associated with new high-tech ventures spun off from universities and research institutes

Novelty of the venture and inexperience of the entrepreneur give rise to a “liability of newness”

- 12, 6 and 3 years experience before founding
- Partners knew each other 6 and 3 years before founding
- Learn software engineering, learn managing a team
  - (as deputy head of department)
- meet clients, learn their needs, keep them also at Math2Market
- Become known to several communities, such as
  - Paper Making
  - Filtration
  - Fuel Cell Materials
  - Metal Wire Mesh

Difficulties associated with new high-tech ventures spun off from universities and research institutes

Evolution from an initial idea in a non-commercial environment to becoming established as a competitive revenue-generating firm.

Many colleagues at Fraunhofer behave like researchers at universities – but this is also true of many researchers in companies. We got lucky that our clients, at least the engineers, think not so differently from ourselves.

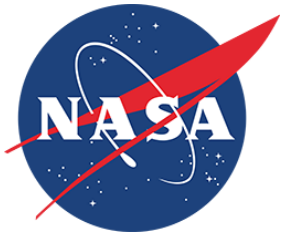
For managers at our clients, it is a different story and to create materials for them required hiring people with a different background than the original founders.

Difficulties associated with new high-tech ventures spun off from universities and research institutes

Conflicting objectives of key stakeholders such as the research institute, the academic entrepreneur, the venture's management team and suppliers of finance

- No external management team, no external supplier of funds
- Biggest issue money: unpaid overtime vs IP belonging to FhG
  - Complex payment involving fixed amount, project work and participation in M2Ms success as well as different numbers of shares
- Even more important than IP
  - M2M were allowed to continue with clients, now even some three-way collaborations Fraunhofer ITWM – M2M – Client
  - FhG provided fall-back solutions, in case of accidents to founders, for example escrow service

Selected Clients of Math2Market GmbH



Selected Clients

Selected Clients

Wir leben Autos.

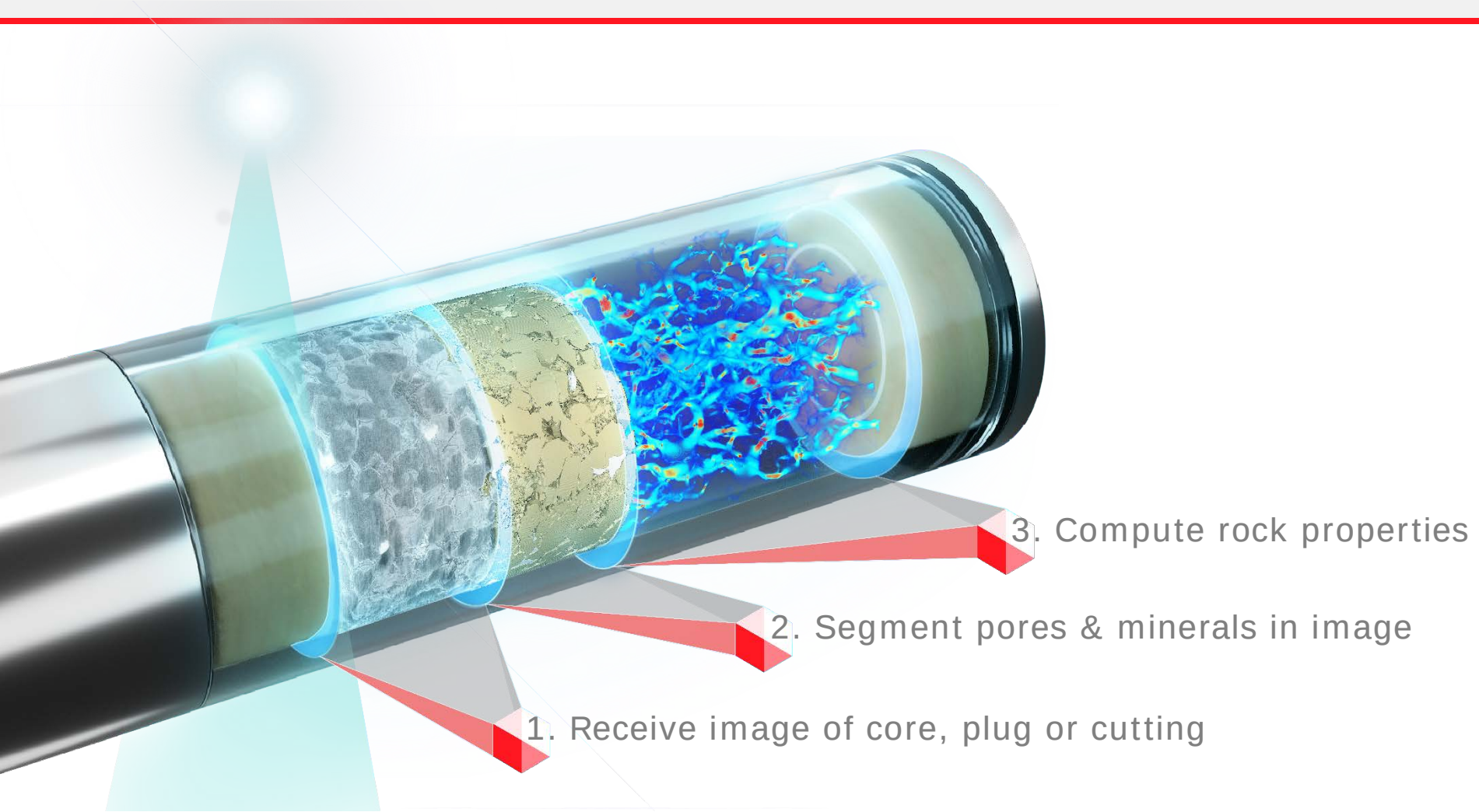
About the need for material modelling and simulation

- The function of porous and composite materials results from the choice of raw materials and their micro structure, i.e. the distribution of the constituents, e.g. fibers, in space.
- The power of simple models to predict the effects of the micro structure is limited.
- µCT and FIB-SEM provide 3D images of existing materials with unprecedented resolution.
- From these, one can compute the material‘s properties to match measured properties.
- Models also convert into 3D images. From these, material properties can be determined without the need to manufacture the new materials first.
- Instead of letting universities or institutes develop next generation materials, companies keep this knowledge in-house, by letting their own employees run the digital experiments.
- The Difficulty of the Math & Software Know-How is such that even the largest companies cannot do it all by themselves.
- 10 of the top 100 market capitalized companies are M2M clients, including Shell and P&G, who introduced the concept of open innovation about 2 decades ago.
- In the future, companies will need to be on top of their materials. The days of trial and error are coming to an end as powerful research tools deliver scientific data of unprecedented depth. [http://www.economist.com/technology-quarterly/2015-12-05/new-materials-for-manufacturing]
- At M2M, we believe this is true for our business areas – the future has already begun!

Math2Market GmbH
Promoted Industries

Filtration	Mostly automotive, filter media & filters for water, sludge, oil, air and fuel
Electrochemistry	Fuel cell media & battery materials, catalyst materials
Composites	CFRP, GFRP, mostly automotive, lightweight materials
Oil and Gas	Digital rock physics, digital sand control

Digital Rock Physics
Basic Workflow



Math2Market GmbH, GeoDict for Oil and Gas: Digital Rock Physics Portfolio

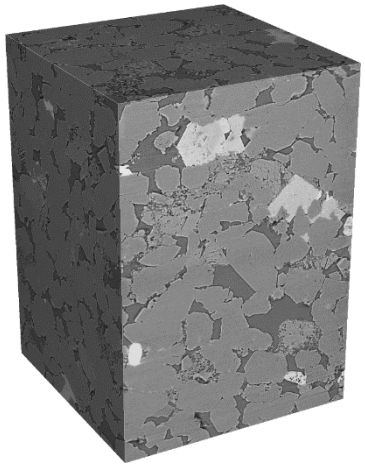
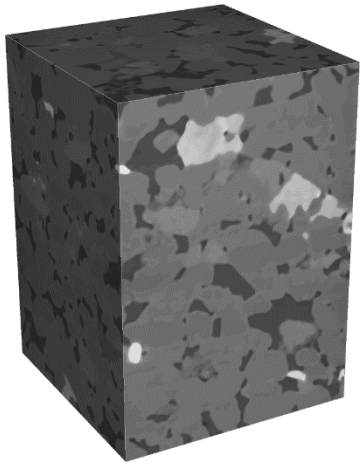
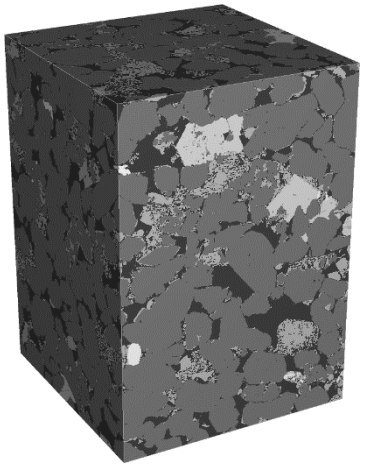
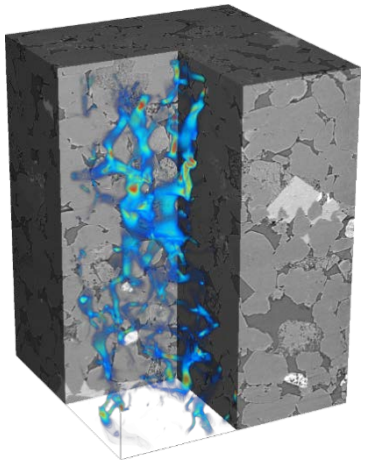
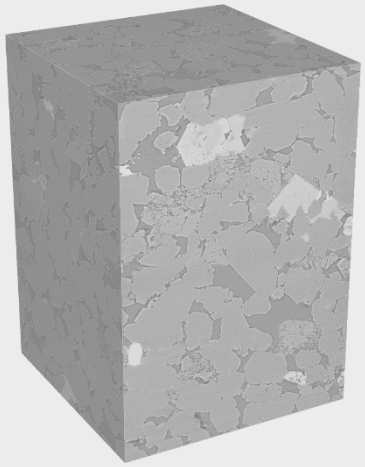
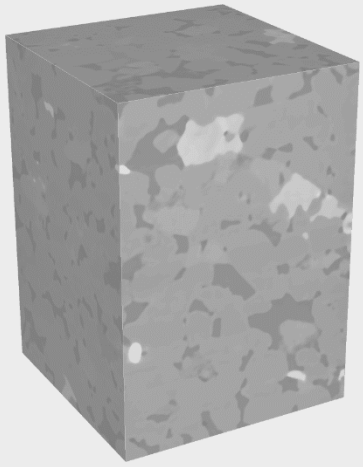
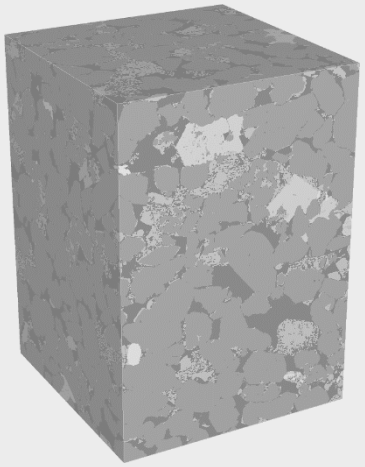





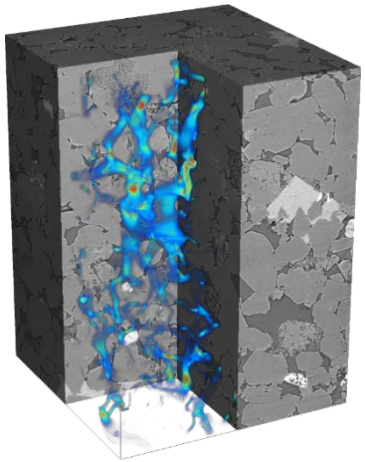
Image import	Image processing	Image segmentation	Property simulations
■ µCT scans ■ Synchrotron CT scans ■ FIB-SEM images ■ Data from other imaging techniques	■ Adjust image size ■ Adjust resolution ■ Non-local means filter ■ Phansalkar filter ■ Sharpening filter	■ Single threshold ■ Multiple threshold ■ Auto-segmentation with Otsu method	■ Geometrical parameters ■ Flow parameters ■ Electrical parameters ■ Mechanical parameters ■ NMR in preparation

Math2Market GmbH, GeoDict for Oil and Gas: Digital Rock Physics Portfolio









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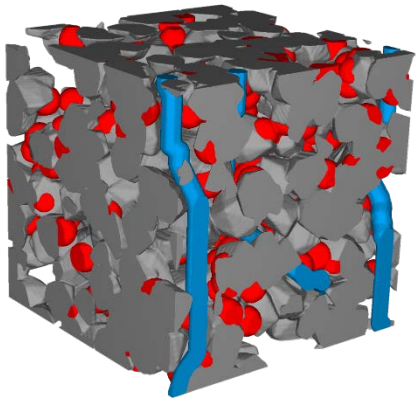
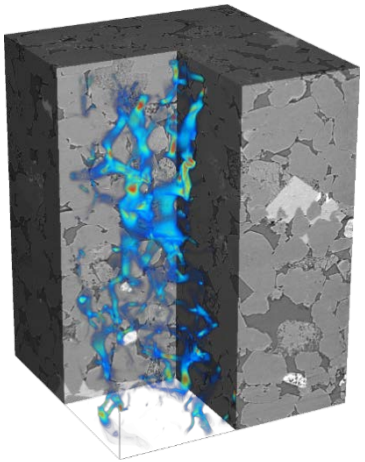
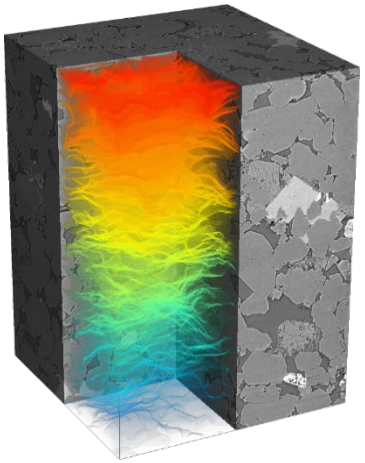
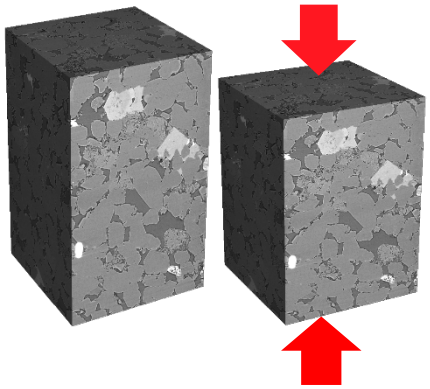


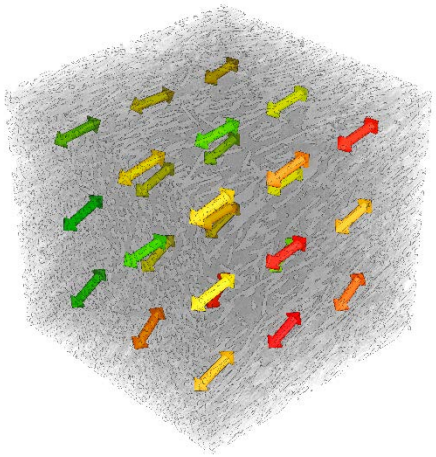


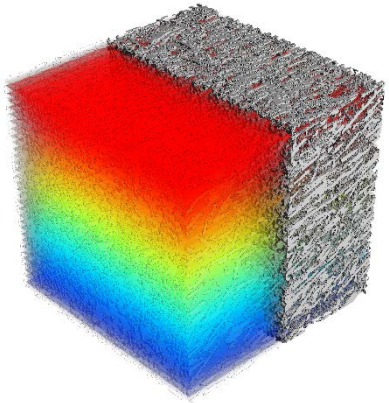


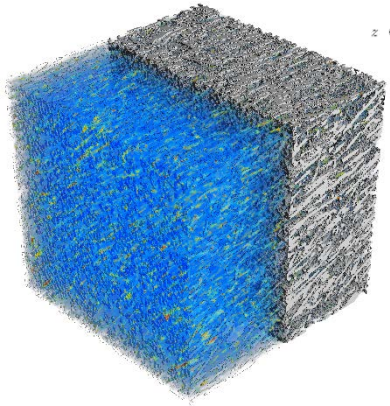


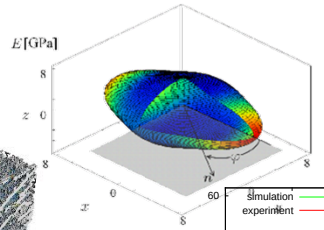
Geometric parameters	Flow parameters	Electrical parameters	Mechanical parameters
■ Porosity	■ Absolute permeability	■ Formation factor	■ Elastic moduli
■ Pore size distribution	■ Upscaling of Flow	■ Resistivity index	■ Stiffness
■ Percolation	■ Multi-phase flow	■ Saturation exponent	■ In-Situ conditions
■ Surface area	■ Relative permeability	■ Cementation exponent	
■ Tortuosity	■ Cap. pressure curve		

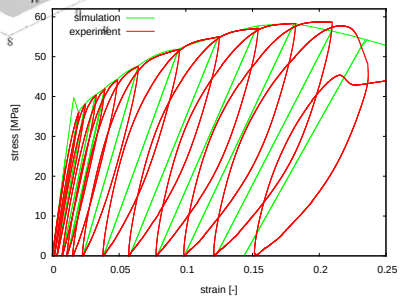
Math2Market GmbH, GeoDict for Composites: Digital Experiments on CT-Scans





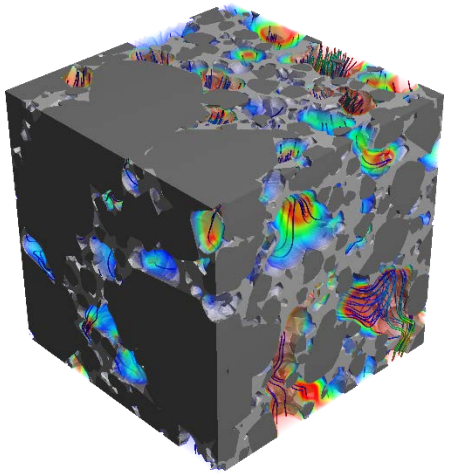
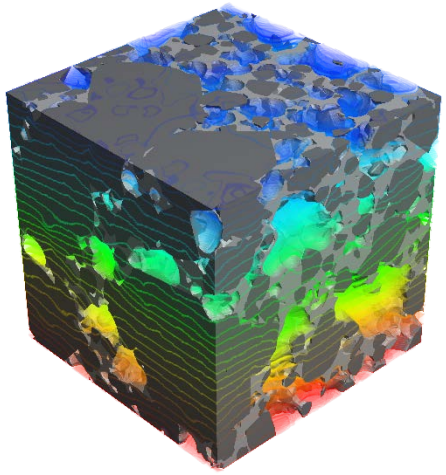
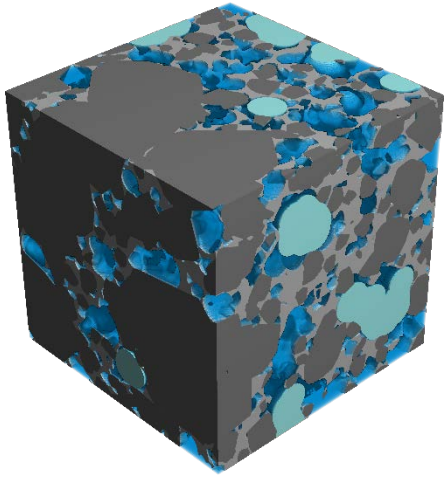
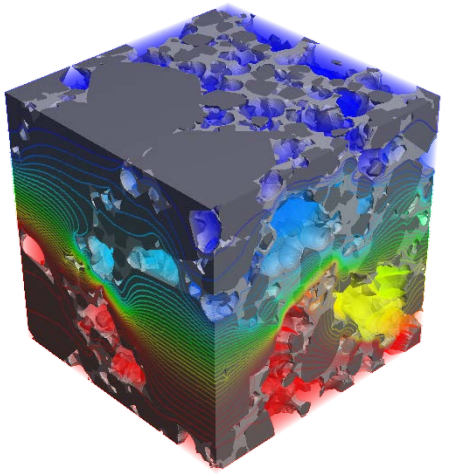






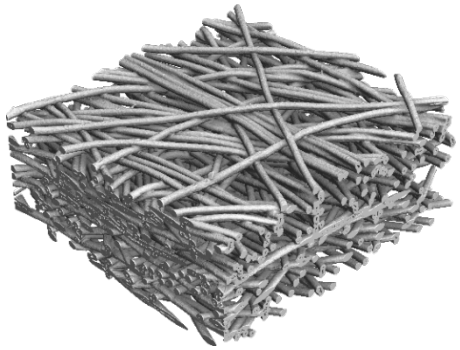
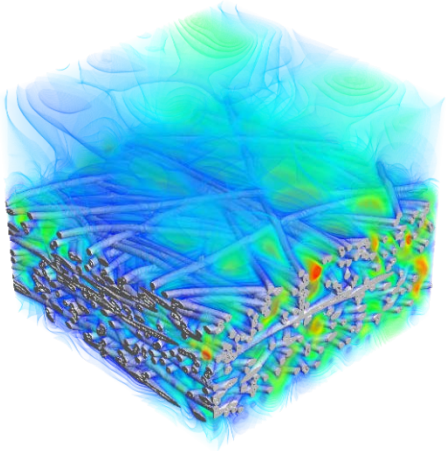
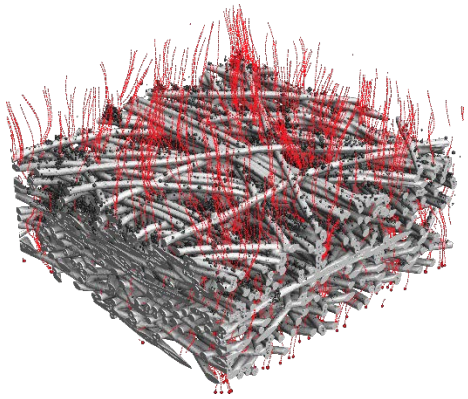
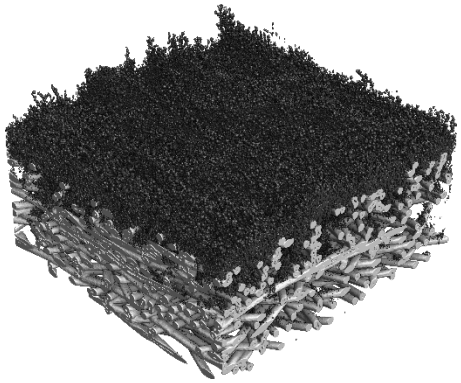
Geometrical Parameters	Flow & Conduction Parameters	Mechanical Parameters	Large Deformation, Damage & Failure
■ Fiber volume fraction	■ Absolute permeability	■ Elastic moduli	■ Hyperelastic materials
■ Fiber diameters	■ Thermal conductivity	■ Stiffness tensor	■ Plastic deformations
■ Fiber orientation	■ Electrical conductivity	■ Full anisotropy	■ Viscous effects
■ 3d structure modelling	■ Tortuosity	■ Thermal expansion	■ Failure and damage
	■ Diffusivity	■ Stress-Strain curves	■ Structure change

Math2Market GmbH, GeoDict for Electrochemistry: Electrode Portfolio

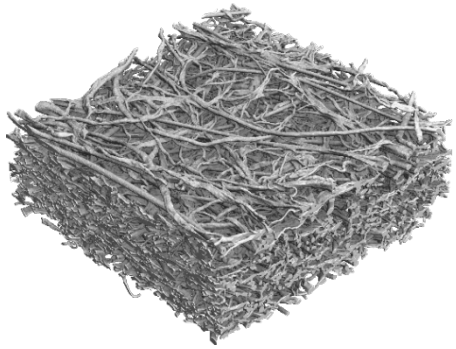
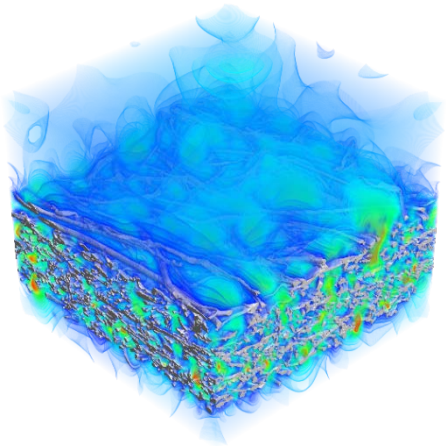
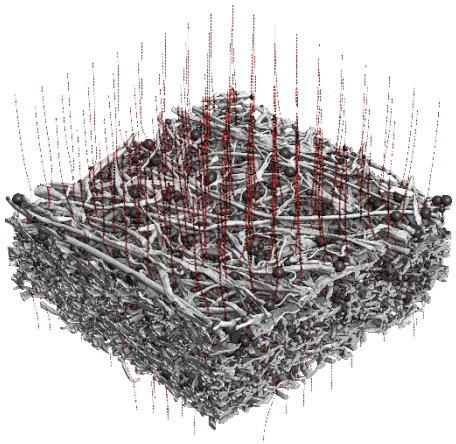
Geometrical parameters	Conduction parameters	Saturation parameters	Diffusion & Flow Parameters
■ Porosity ■ Pore size distribution ■ Surface area ■ Length of contact lines ■ Tortuosity/Gurley value	■ Thermal conductivity ■ Thermal Flux ■ Temperature distribution ■ Electrical conductivity ■ Electrical Flux ■ Electrostatic potential distribution	■ Saturation exponent ■ Variable contact angles ■ Cap. pressure curve	■ Permeability ■ Diffusivity ■ Particle concentration ■ Path of single particle

Math2Market GmbH, GeoDict for Filtration: Gas Filtration Portfolio

Filter Media	Clean Filter Parameters	Gas Filtration Experiments	Gas Filtration Results
■ Nonwoven fabrics ■ Woven fabrics ■ Foams ■ Sintered ceramics ■ Pleats and support meshes	■ Media thickness ■ Fiber diameters ■ Fiber orientation ■ Grammage ■ Pore size distribution ■ Bubble point ■ Percolation path	■ Single pass tests ■ Diesel soot test dust ■ Standard aerosol test dusts	■ Initial pressure drop ■ Pressure drop evolution ■ Initial filter efficiency ■ Fractional efficiencies ■ Filter capacity ■ Filter class ■ Most penetrating particle size

Math2Market GmbH, GeoDict for Filtration: Liquid Filtration Portfolio

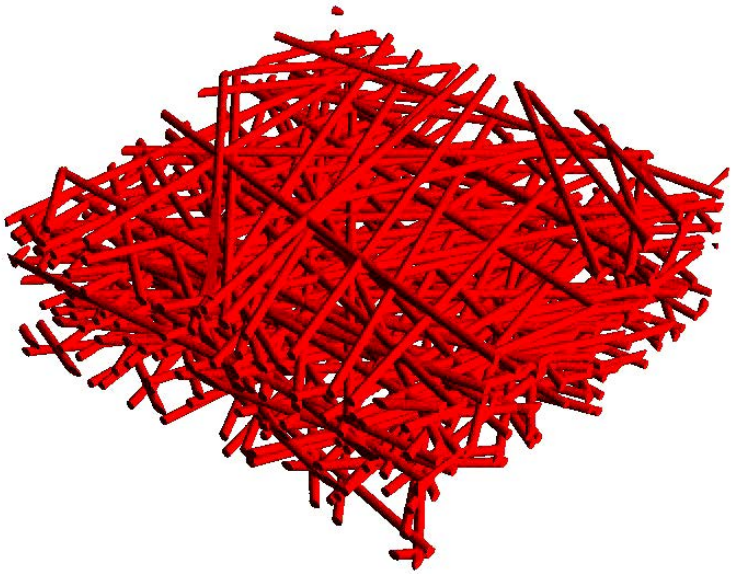





Filter Media	Clean Filter Parameters	Liquid Filtration Experiments	Liquid Filtration Results
■ Nonwoven fabrics	■ Media thickness	■ Multi pass tests	■ Initial pressure drop
■ Woven fabrics	■ Fiber diameters	■ Standard test dusts	■ Pressure drop evolution
■ Foams	■ Fiber orientation		■ Initial filter efficiency
■ Membranes	■ Grammage		■ Fractional efficiencies
■ Metal wire meshes	■ Pore size distribution		■ Filter capacity
■ Pleats & support meshes	■ Bubble point		■ Filter class
	■ Percolation path		■ Filter clogging behavior

Creating 3D Structure Models

Input parameters needed (straight fibers):

- Porosity
- Fiber type: cross sectional shape, diameter, length
- Fiber orientation tensor
- Thickness (height) of the filter media

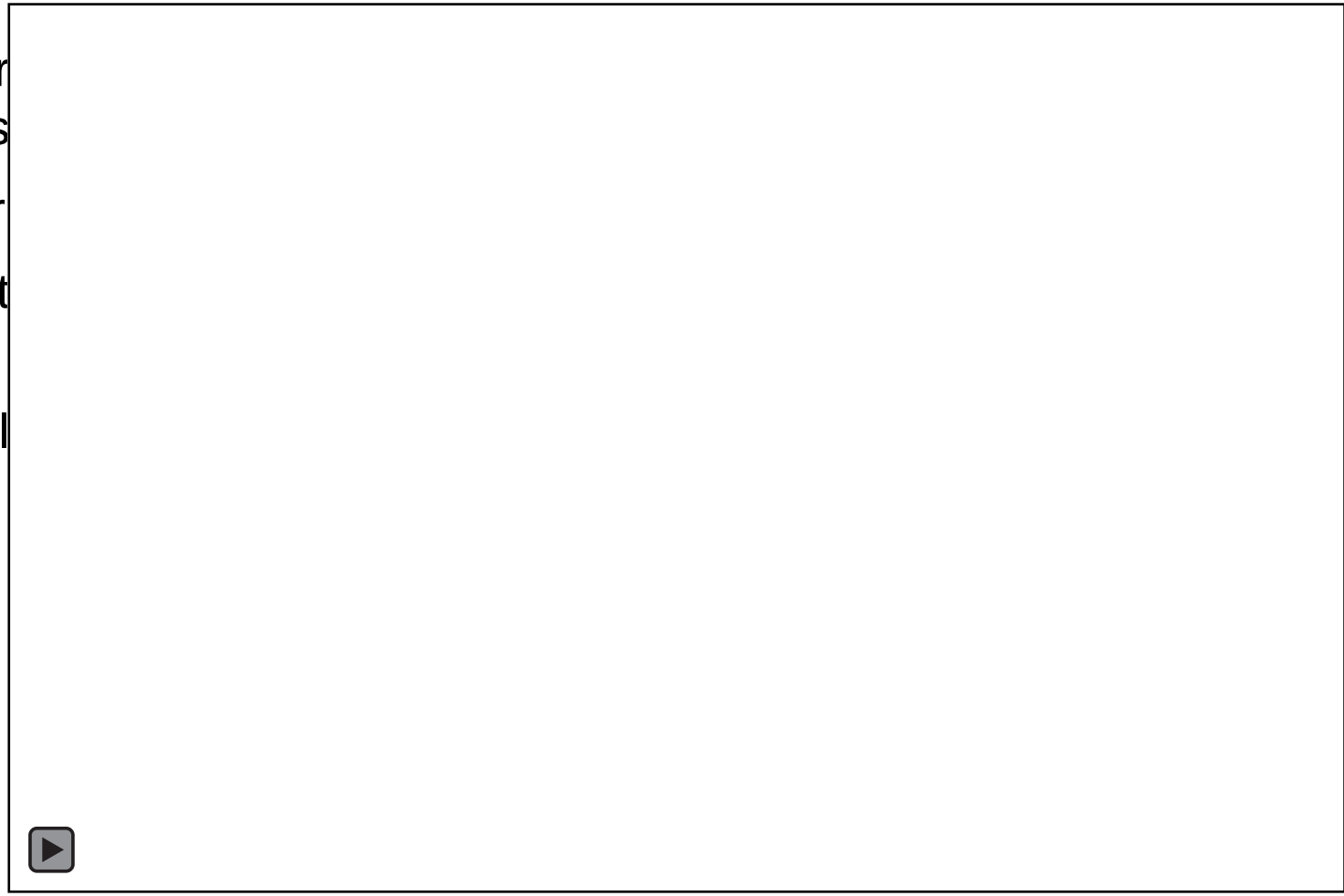


Parameters might be

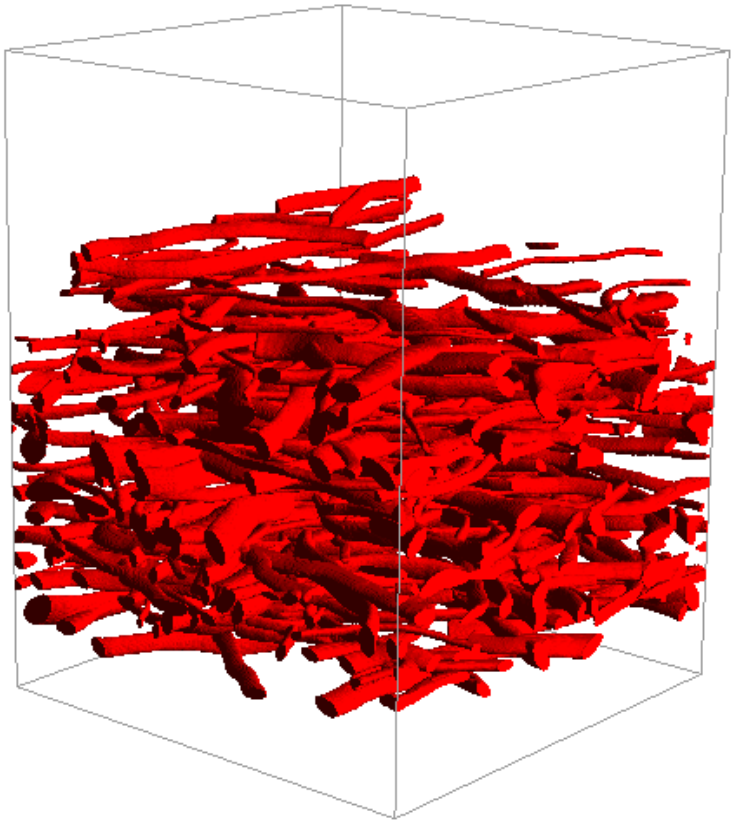
- known from manufacturing process
- measured experimentally
- measured from CT image

Oil Filter model

- Ellipsoidal cr
  diameter dis
- Curved fiber
- Fibers orient
- 500 x 500 x
  1 µm voxel l



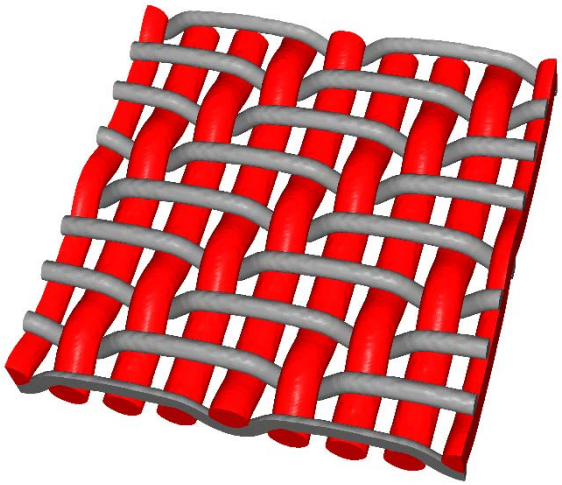
Create cellulose and layered media scale models



Cellulose nonwoven

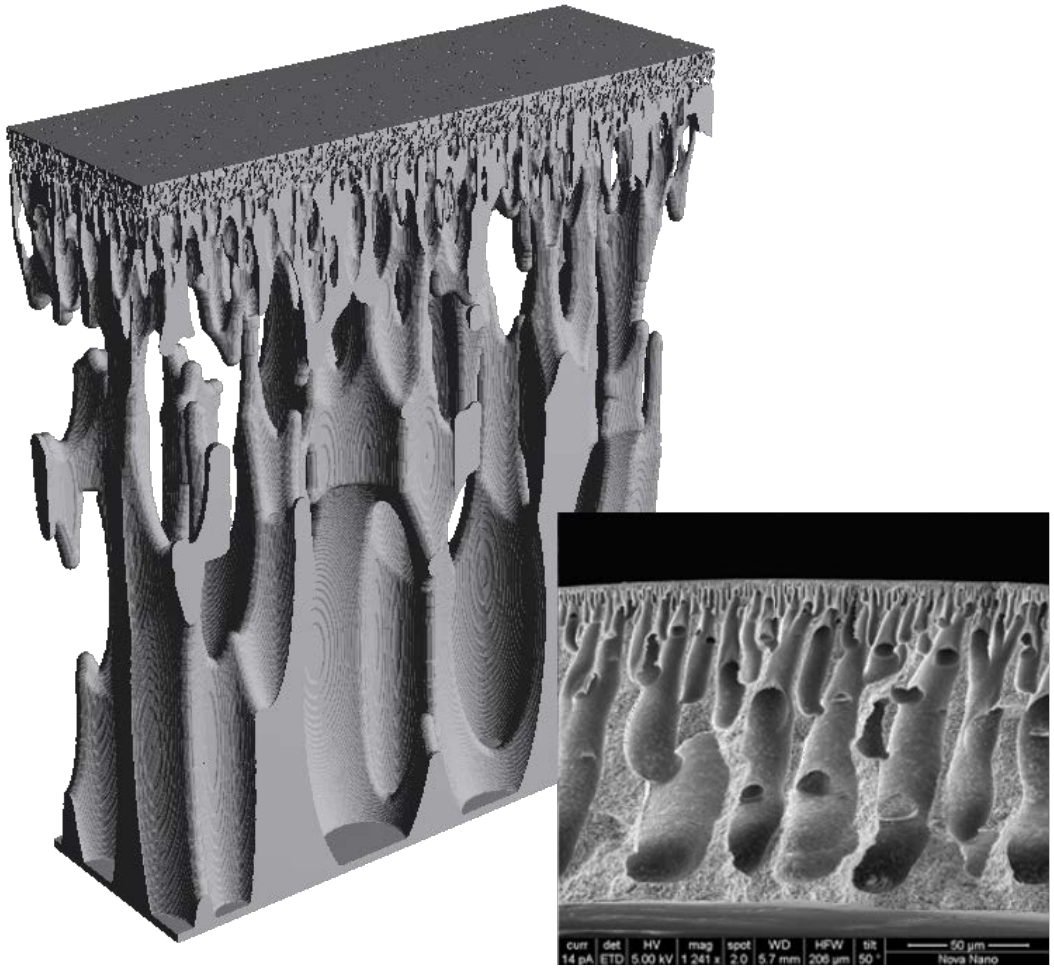
Layered filter medium

Create woven, foam and sintered media scale models



Metal wire mesh | Open-cell foam | Sintered ceramics

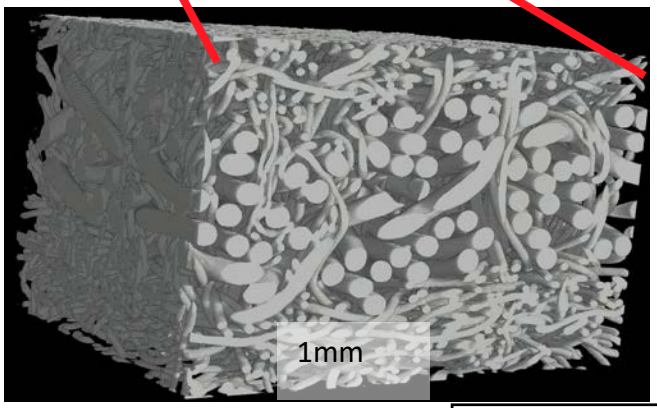
model a desalination membrane from a SEM image



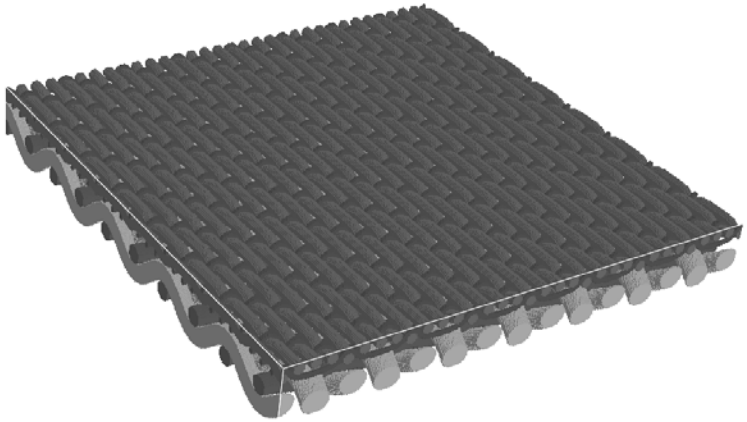
http://www.geodict.com/Showroom/structures.php

Tomography and Models of Felts

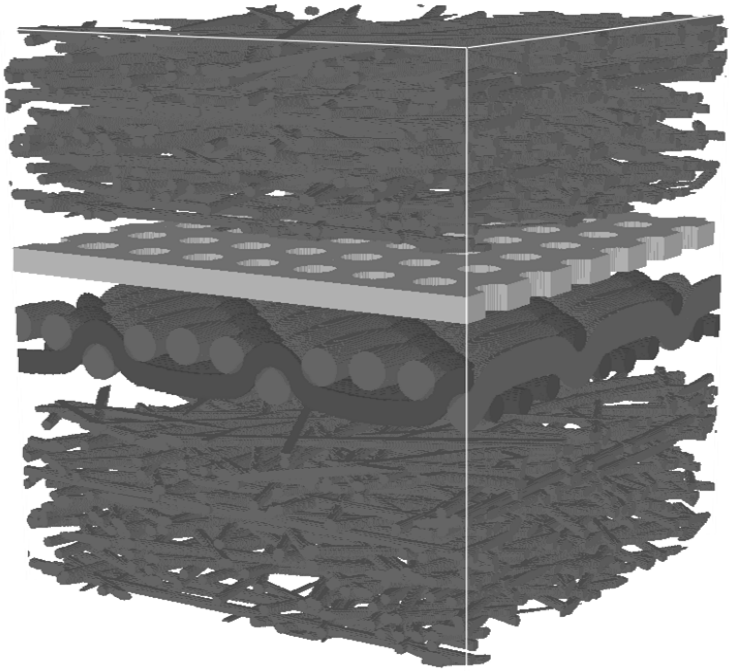
Paper machine



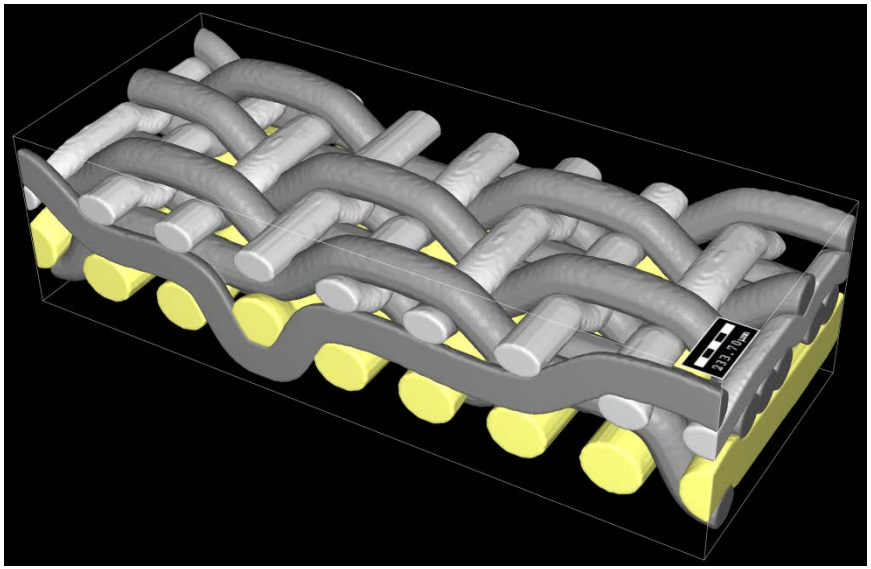
Tomography

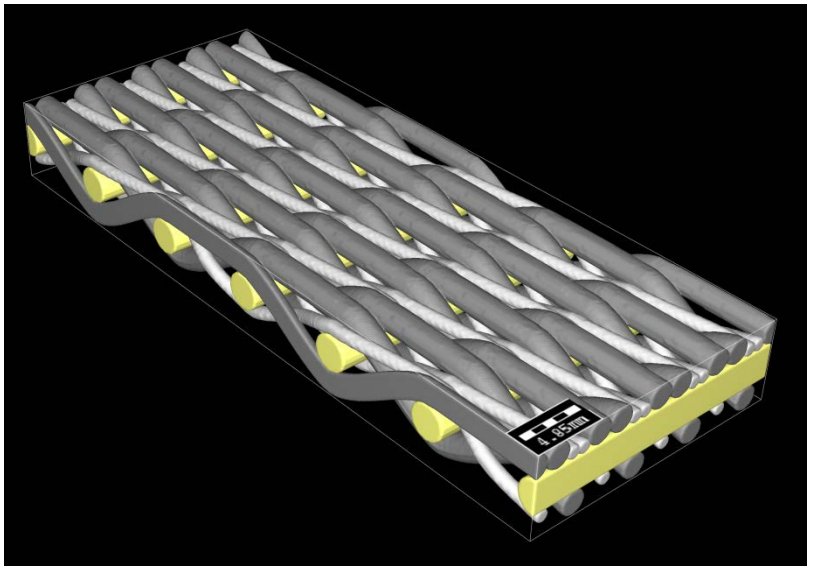


Forming fabric and dewatering felt



Woven Metal Wire Meshes: Complex weave models

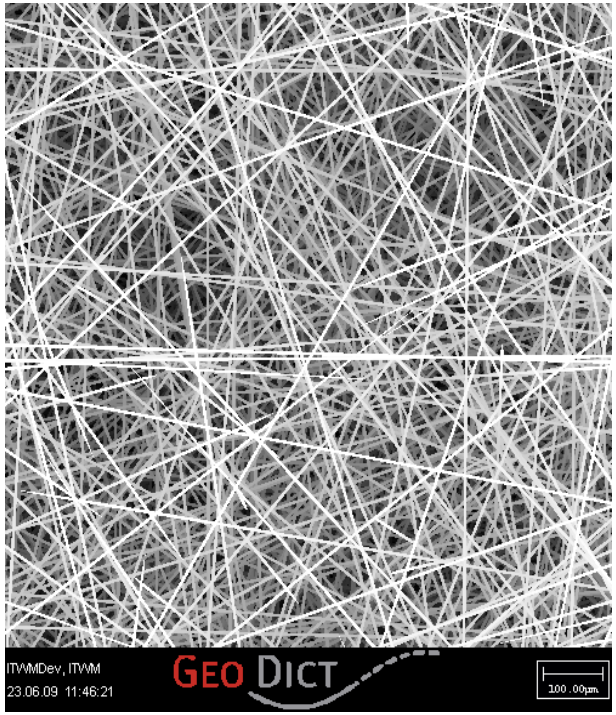




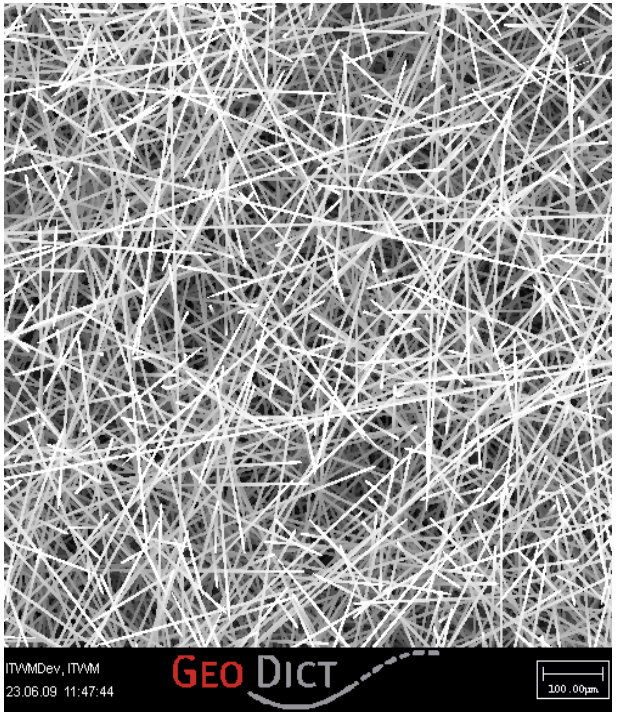
Left: Model of a two-layer weave based on a CT-scan.
Right: Model of a complex one-layer twill Dutch-weave.

Glass fiber nonwoven

SEM visualization of 8 volume percent 5 micron fibers

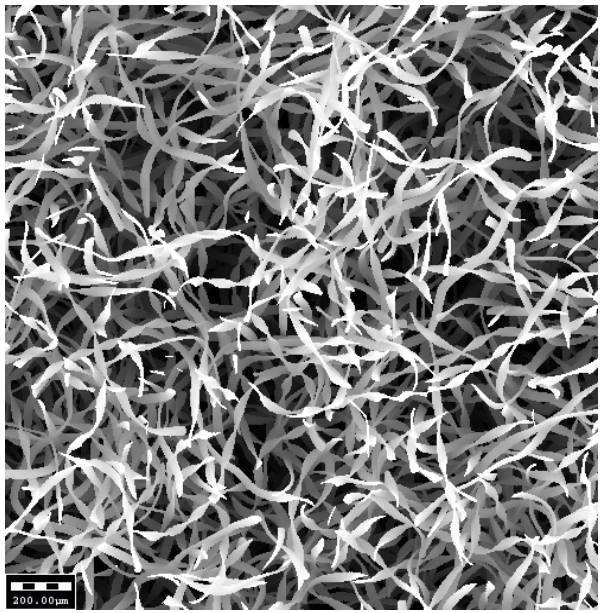


anisotropy 100

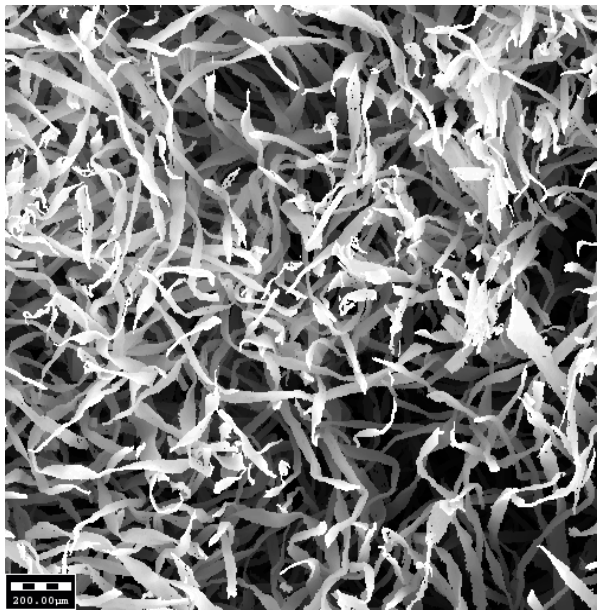


anisotropy 7

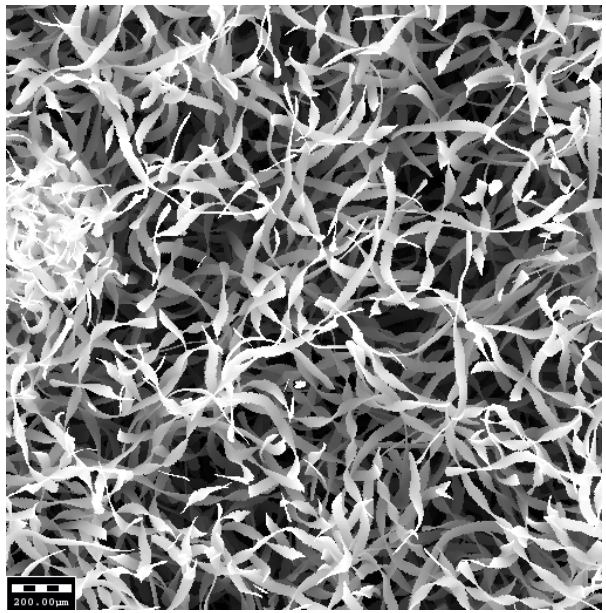
Curled & inhomogeneous nonwoven



homogeneous model



µCT scan



inhomogeneous model

Simulation provides deposition location details over time. Distinguishes depth filtration and cake filtration phases.

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