Nanotechnology Applied in the Future Thermal Insulation Materials for Buildings

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References:

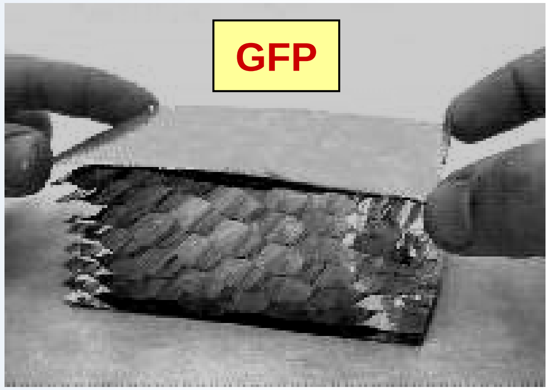
- B. P. Jelle, A. Gustavsen and R. Baetens, "The Path to the High Performance Thermal Building Insulation Materials and Solutions of Tomorrow", Accepted for publication in *Journal of Building Physics*, 2010.
- B. P. Jelle, A. Gustavsen, R. Baetens and S. Grynning, "Nano Insulation Materials Applied in the Buildings of Tomorrow", *Proceedings of COIN Workshop on Concrete Ideas for Passive Houses*, Oslo, Norway, 26-27 January, 2010.
- B. P. Jelle, A. Gustavsen, S. Grynning and R. Baetens, "How Might Nano Technology Improve the Thermal Performance of the Concrete Buildings of Tomorrow?", *Proceedings of COIN Workshop on Concrete Ideas for Passive Houses*, Oslo, Norway, 26-27 January, 2010.

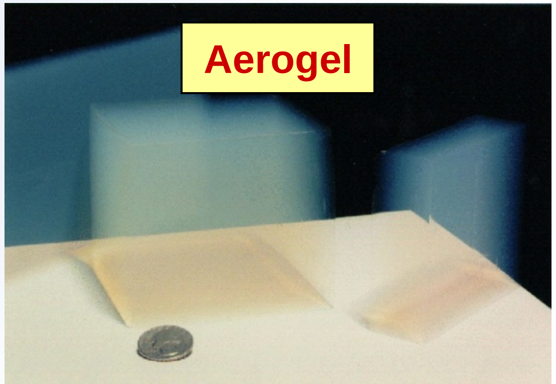
Tekna Seminar – Nanotechnology in Buildings, Oslo, 11th of November, 2010.

State-of-the-Art Thermal Insulation of Today

- What is Out There?

- **Vacuum Insulation Panels (VIP)**
  "An evacuated foil-encapsulated open porous material as a high performance thermal insulating material"
  - Core (silica, open porous, vacuum)
  - Foil (envelope)
- **Gas-Filled Panels (GFP)**
- **Aerogels**
- **Phase Change Materials (PCM)**
  - Solid State ↔ Liquid
  - Heat Storage and Release
- **Beyond State-of-the-Art High Performance Thermal Insulation Materials**

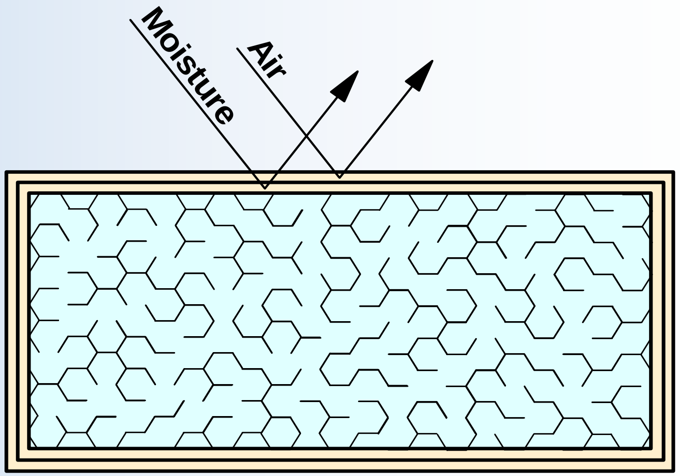




Thermal Insulation of Today

- Traditional Insulation
  - 36 mW/(mK)
- Vacuum Insulation Panels (VIP)
  - 4 mW/(mK) fresh
  - 8 mW/(mK) 25 years
  - 20 mW/(mK) perforated
- Gas-Filled Panels (GFP)
  - 40 mW/(mK)
- Aerogels
  - 13 mW/(mK)
- (Phase Change Materials (PCM))
- Other Materials and Solutions?

- Vacuum Core
- Air and Moisture Tight Envelope

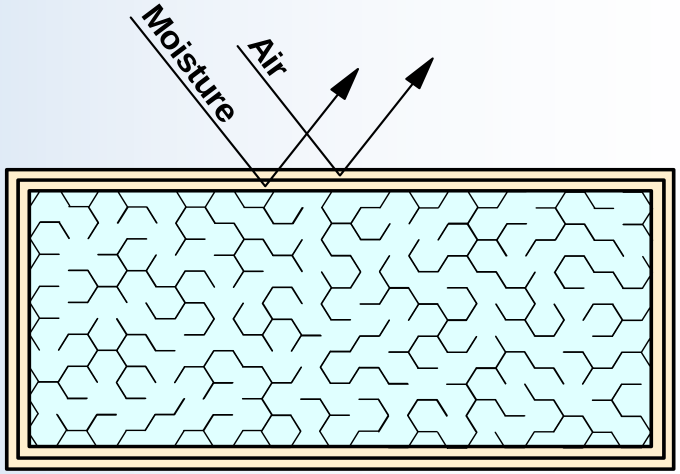


VIP

Major Disadvantages of VIPs

- Thermal bridges at panel edges
- Expensive at the moment, but calculations show that VIPs may be cost-effective even today
- Ageing effects - Air and moisture penetration
  - 4 mW/(mK) fresh
  - 8 mW/(mK) 25 years
  - 20 mW/(mK) perforated
- Vulnerable towards penetration, e.g nails
  - 20 mW/(mK)
- Can not be cut or adapted at building site
- Possible improvements?

- Vacuum Core
- Air and Moisture Tight Envelope



VIP

VIPs – The Thermal Insulation of Today ?

- VIPs - Despite large disadvantages - A large leap forward
- Thermal conductivities 5 to 10 times lower than traditional insulation
  - 4 mW/(mK) fresh
  - 8 mW/(mK) 25 years
  - 20 mW/(mK) perforated
- Wall and roof thicknesses up to 50 cm as with traditional insulation are not desired
  - Require new construction techniques and skills
  - Transport of thick building elements leads to increased costs
- Building restrictions during retrofitting of existing buildings
  - Lawful authorities
  - Practical Restrictions
- High living area market value per $m^2 \Rightarrow$ Reduced wall thickness $\Rightarrow$ Large area savings $\Rightarrow$ Higher value of the real estate
- VIPs - The best solution today and in the near future?
- Beyond VIPs?

Requirements of the Thermal Insulation of Tomorrow

Property	Requirements
Thermal conductivity – pristine	< 4 mW/(mK)
Thermal conductivity – after 100 years	< 5 mW/(mK)
Thermal conductivity – after modest perforation	< 4 mW/(mK)
Perforation vulnerability	not to be influenced significantly
Possible to cut for adaption at building site	yes
Mechanical strength (e.g. compression and tensile)	may vary
Fire protection	may vary, depends on other protection
Fume emission during fire	any toxic gases to be identified
Climate ageing durability	resistant
Freezing/thawing cycles	resistant
Water	resistant
Dynamic thermal insulation	desirable as an ultimate goal
Costs vs. other thermal insulation materials	competitive
Environmental impact (including energy and material use in production, emission of polluting agents and recycling issues)	low negative impact

Properties of Concrete
– A Construction Material

- **Thermal Conductivity**

- **Concrete**
  - **150 – 2500 mW/(mK)**

- **Traditional Thermal Insulation**
  - **36 mW/(mK)**

- **Vacuum Insulation Panels (VIPs)**
  - **4 mW/(mK)**

Properties of Concrete

Some key properties of concrete (example values)

Property	With Rebars	Without Rebars
Mass density (kg/dm^3)	2.4	2.2
Thermal conductivity (mW/mK)	2500	1700
Specific heat capacity (J/(kgK))	840	880
Linear thermal expansion coefficient (10^{-6}/K)	12	12
Compressive strength (MPa)	30	30
Tensile strength (MPa) [a]	500 [b]	3
Fire resistance	> 2 h	> 2 h
Environmental impact (incl. energy and material use in production, emission of polluting agents and recycling issues)	large CO_2 emissions	large CO_2 emissions

[a] As a comparison, note that carbon nanotubes have been manufactured with tensile strengths as high as 63 000 MPa and have a theoretical limit at 300 000 MPa. [b] Rebars.

Environmental Impact of Concrete

Large CO_2 emissions from cement production

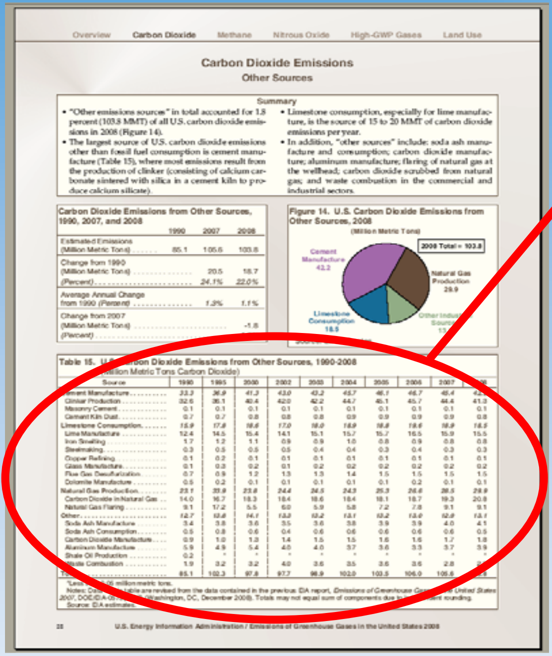


Table 15. U.S. Carbon Dioxide Emissions from Other Sources, 1990-2008
(Million Metric Tons Carbon Dioxide)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Cement Manufacture	*33.3*	*36.9*	*41.3*	*43.0*	*43.2*	*45.7*	*46.1*	*46.7*	*45.4*	*42.2*
Clinker Production	32.6	36.1	40.4	42.0	42.2	44.7	45.1	45.7	44.4	41.3
Masonry Cement	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cement Kiln Dust	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.8
Limestone Consumption	*15.9*	*17.8*	*18.6*	*17.0*	*18.0*	*18.9*	*18.8*	*19.6*	*18.9*	*18.5*
Lime Manufacture	12.4	14.5	15.4	14.1	15.1	15.7	15.7	16.5	15.9	15.5
Iron Smelting	1.7	1.2	1.1	0.9	0.9	1.0	0.8	0.9	0.8	0.8
Steelmaking	0.3	0.5	0.5	0.5	0.4	0.4	0.3	0.4	0.3	0.3
Copper Refining	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Glass Manufacture	0.1	0.3	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Flue Gas Desulfurization	0.7	0.9	1.2	1.3	1.3	1.4	1.5	1.5	1.5	1.5
Dolomite Manufacture	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Natural Gas Production	*23.1*	*33.9*	*23.8*	*24.4*	*24.5*	*24.3*	*25.3*	*26.6*	*28.5*	*29.9*
Carbon Dioxide in Natural Gas	14.0	16.7	18.3	18.4	18.6	18.4	18.1	18.7	19.3	20.8
Natural Gas Flaring	9.1	17.2	5.5	6.0	5.9	5.8	7.2	7.8	9.1	9.1
Other	*12.7*	*13.8*	*14.1*	*13.3*	*13.2*	*13.1*	*13.2*	*13.0*	*12.9*	*13.1*
Soda Ash Manufacture	3.4	3.8	3.6	3.5	3.6	3.8	3.9	3.9	4.0	4.1
Soda Ash Consumption	0.5	0.8	0.6	0.4	0.6	0.6	0.6	0.6	0.6	0.5
Carbon Dioxide Manufacture	0.9	1.0	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.8
Aluminum Manufacture	5.9	4.9	5.4	4.0	4.0	3.7	3.6	3.3	3.7	3.9
Shale Oil Production	0.2	*	*	*	*	*	*	*	*	*
Waste Combustion	1.9	3.2	3.2	4.0	3.6	3.5	3.6	3.6	2.8	2.8
Total	85.1	102.3	97.8	97.7	98.9	102.0	103.5	106.0	105.6	103.8

*Less than 0.05 million metric tons.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

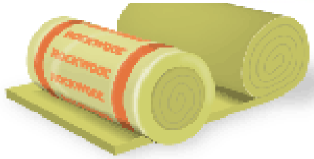
P. McArdle and P. Lindstrom, "Emissions of greenhouse gases in the United States 2008", U.S. Energy Information Administration, DOE/EIA-0573(2008), December 2009.

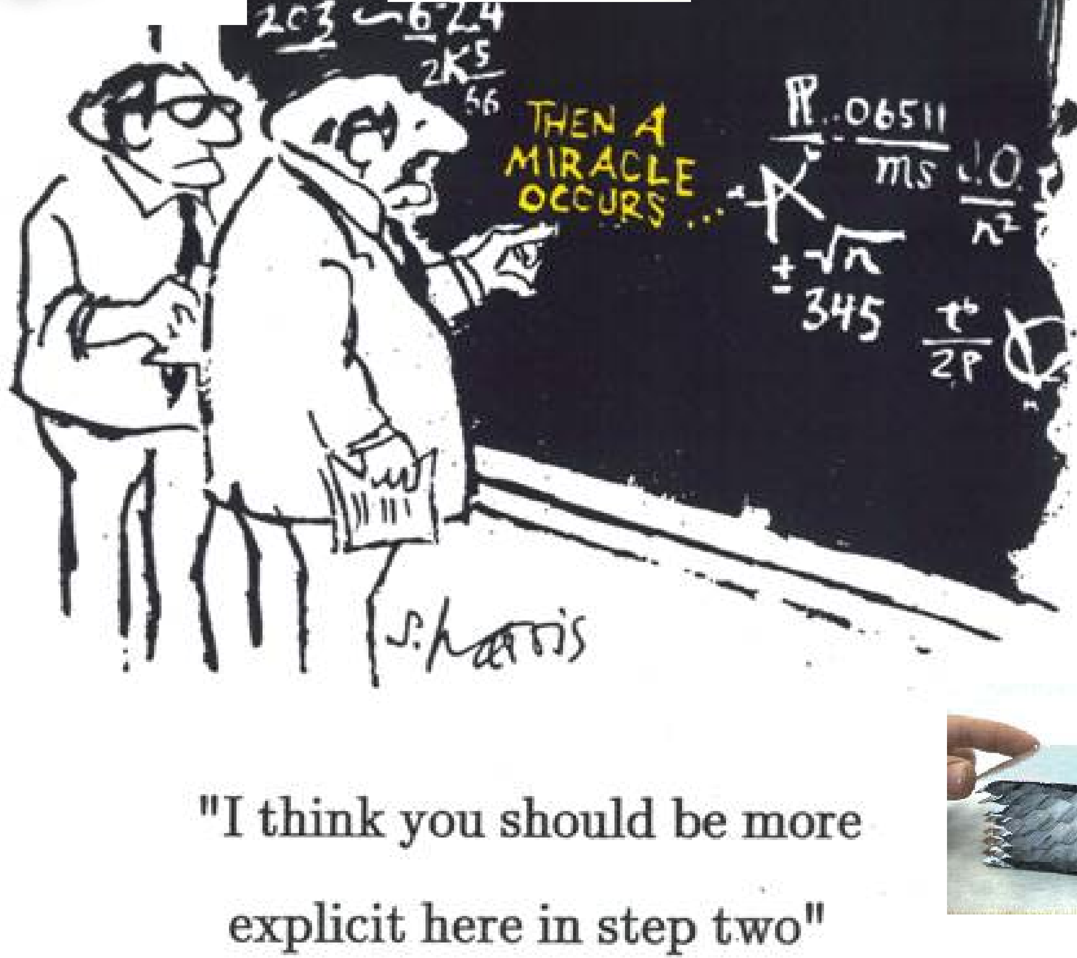
Large CO_2 Emissions from Cement Production

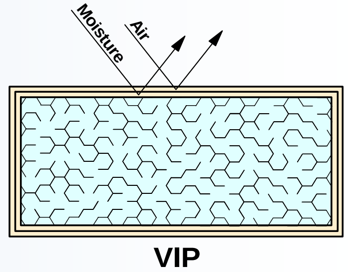
- The cement industry produces 5 % of the global man-made CO_2 emissions of which:
- 50 % from the chemical process
  - e.g.: $3CaCO_3 + SiO_2 \rightarrow Ca_3SiO_5 + 3CO_2$
    $2CaCO_3 + SiO_2 \rightarrow Ca_2SiO_4 + 2CO_2$
- 40 % from burning fossil fuels
  - e.g. coal and oil
- 10 % split between electricity and transport uses

World Business Council for Sustainable Development, ”The cement sustainability initiative – Our agenda for action”, July 2002.

Beyond Traditional Thermal Insulation?







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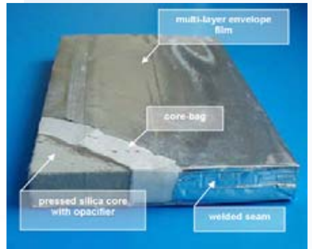
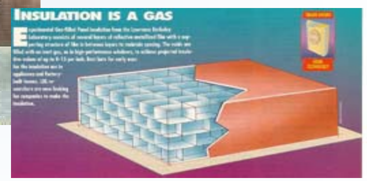
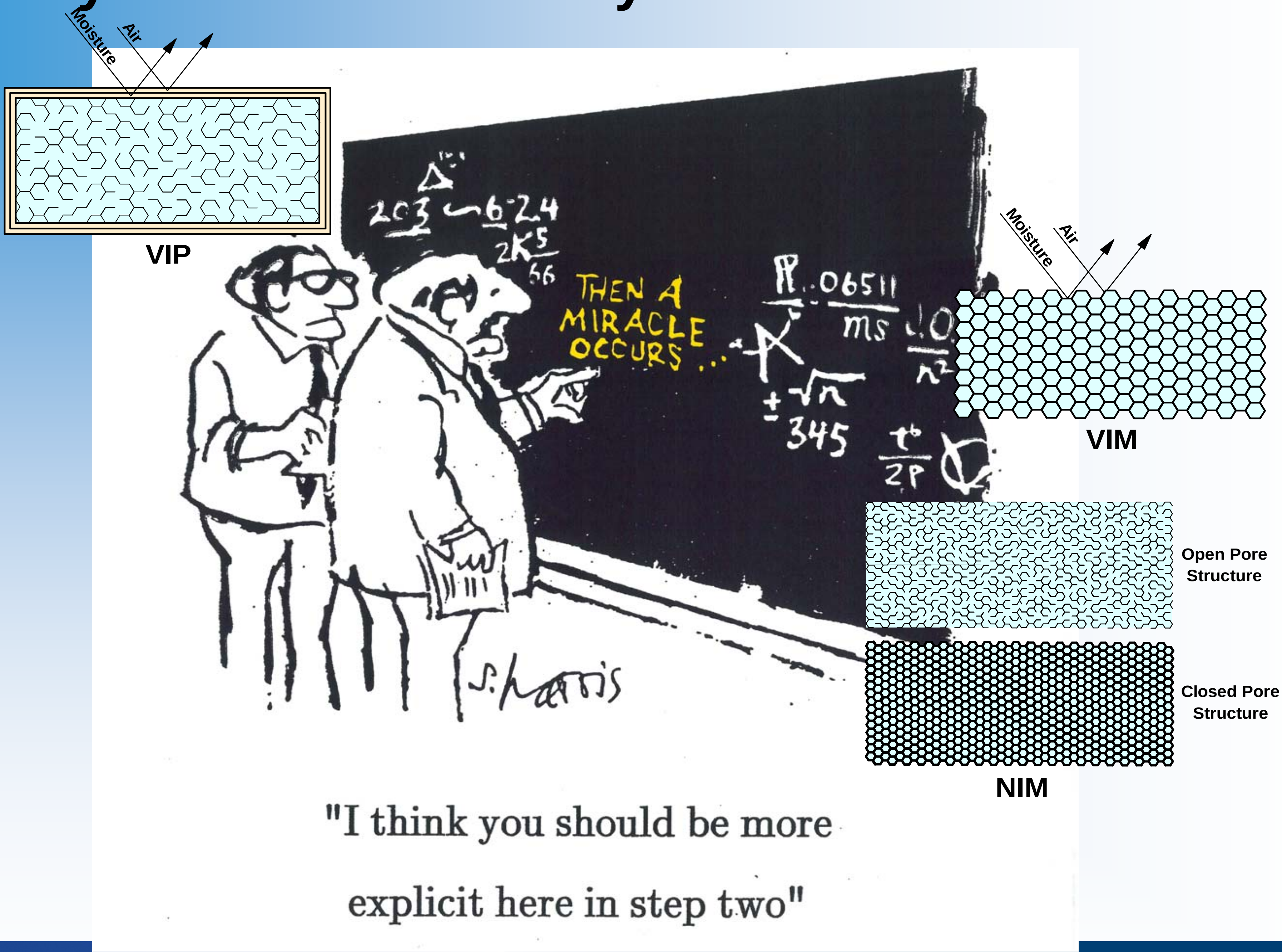


VIP
GFP

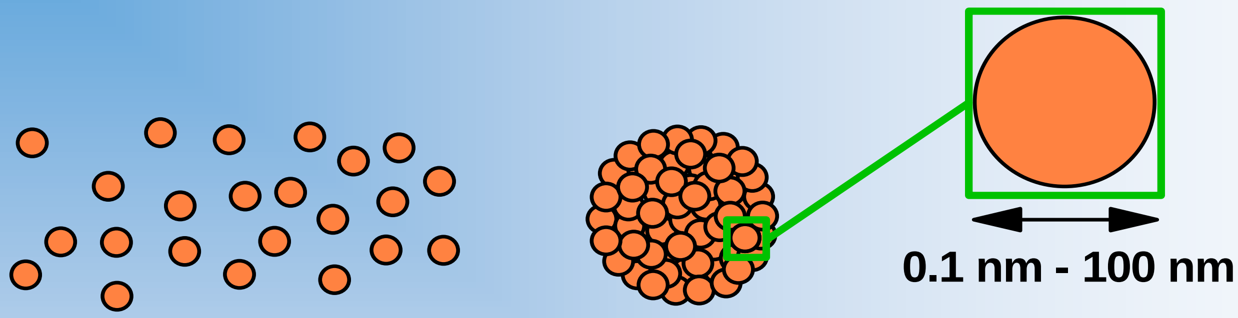


Beyond VIPs – How May It Be Achieved?



Nano Technology

Nanotechnology:
Technology for controlling matter of dimensions between 0.1 nm - 100 nm.



For comparison:

Solar radiation: 300 nm - 3000 nm

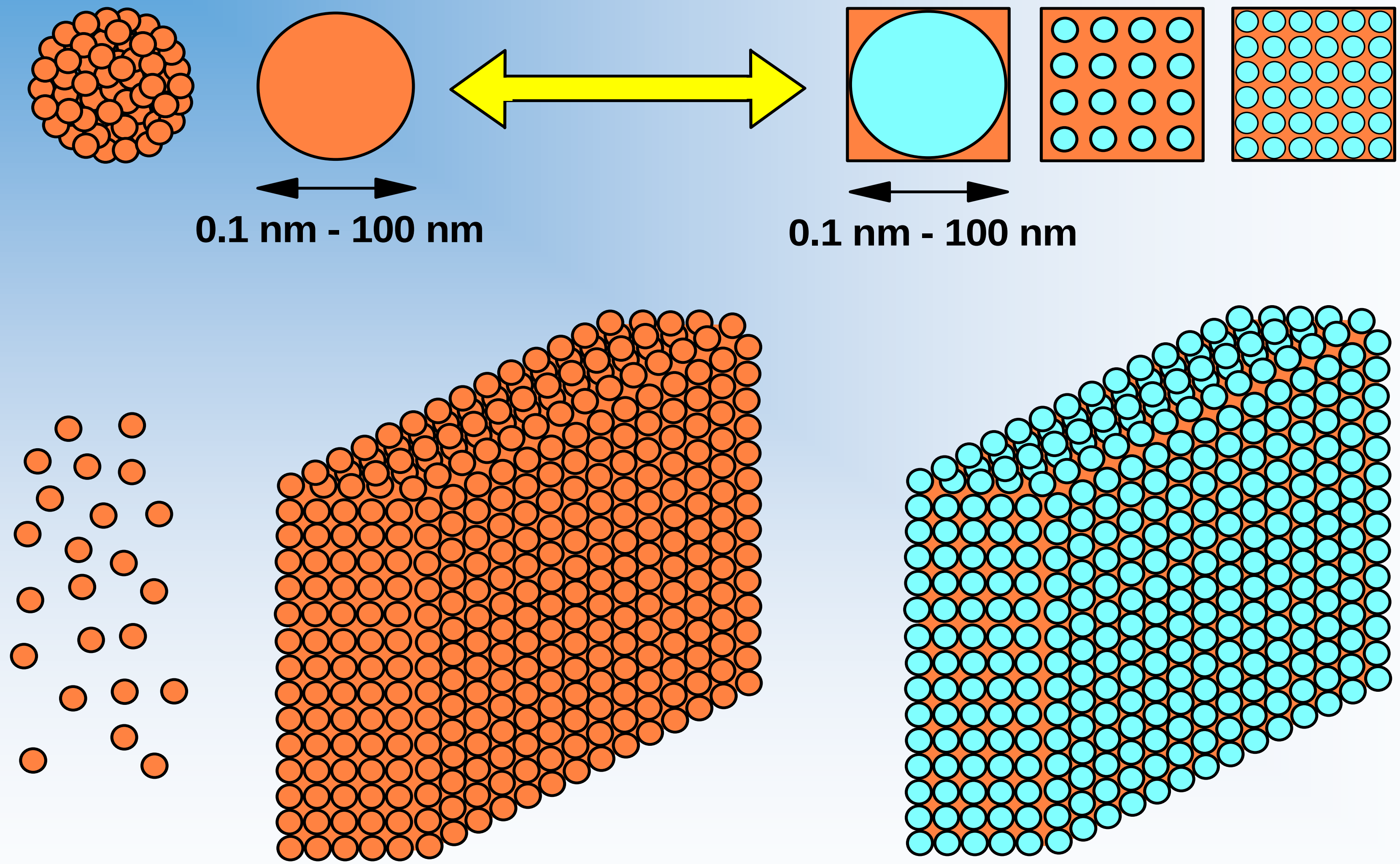
Atomic diameters: Hydrogen: 0.16 nm
Carbon: 0.18 nm
Gold: 0.36 nm

Molecular length: Stearic Acid: 2.48 nm
($C_{17}H_{35}COOH$)

Nanotechnology:
Technology for controlling matter at an atomic and molecular scale.

Nano Technology and Thermal Insulation

Nano Particles | **Nano Pores**

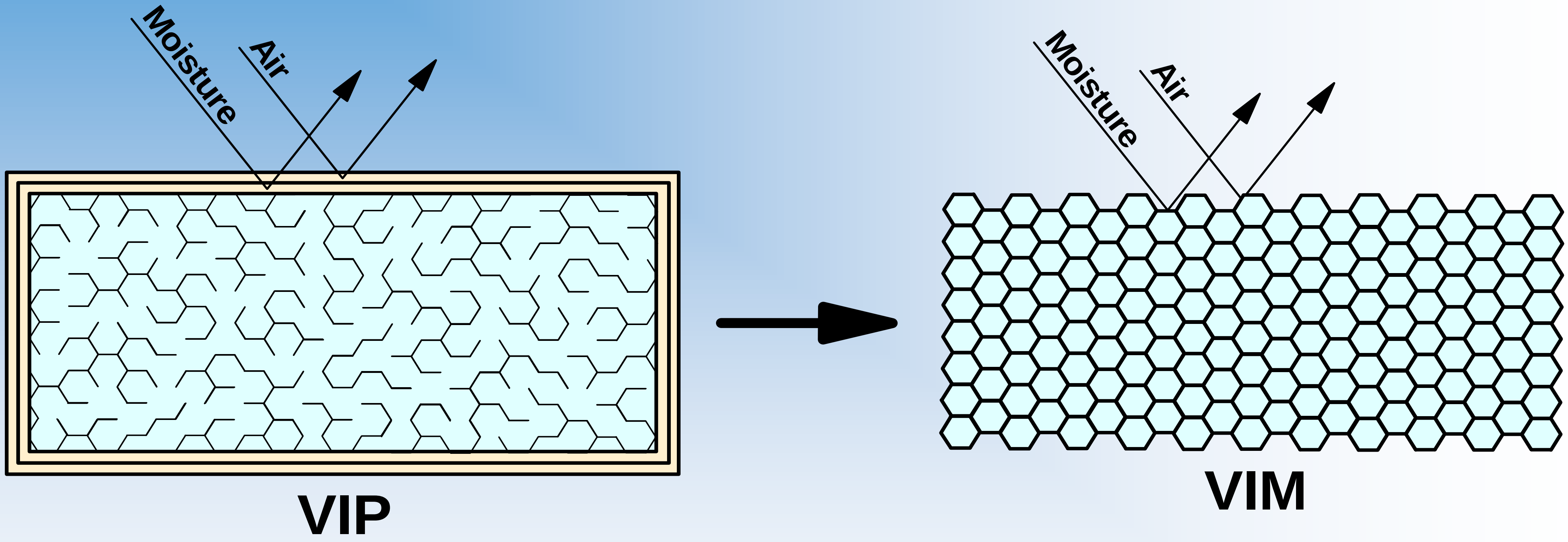


Beyond VIPs – How May It Be Achieved?

Introducing New Concepts as

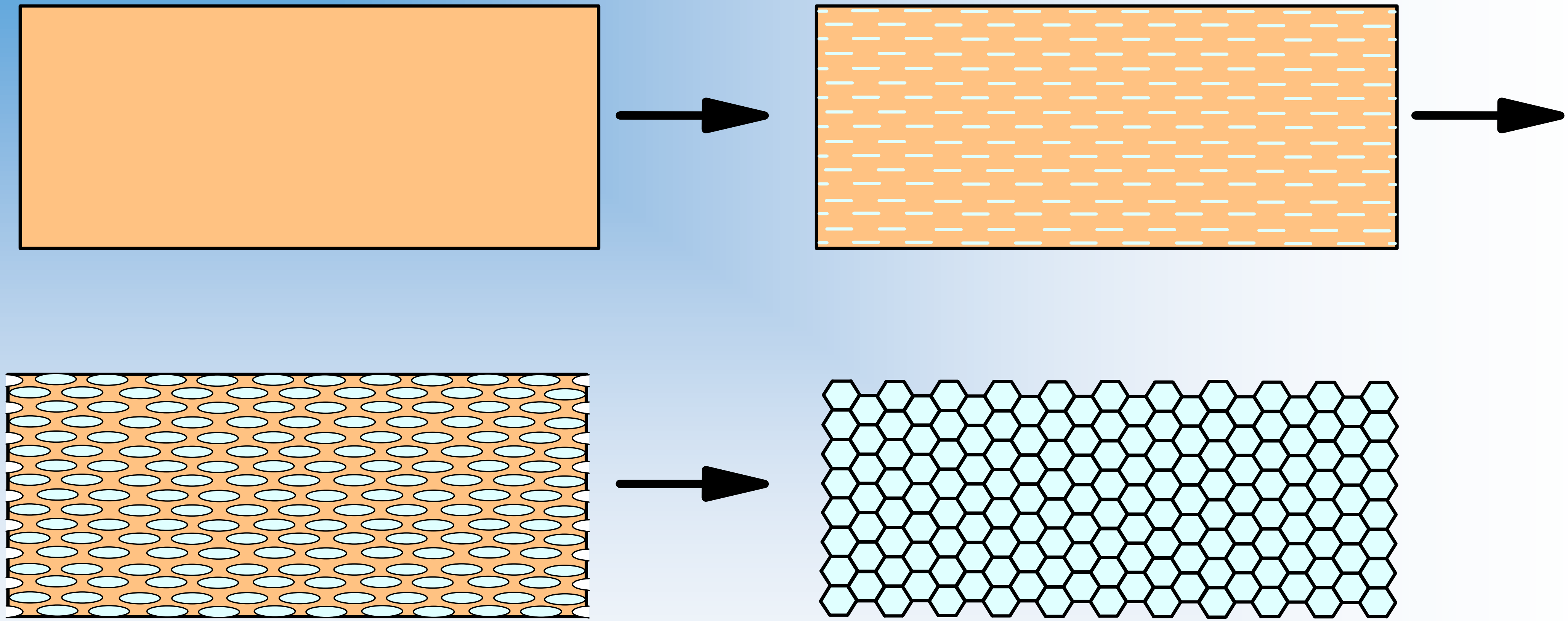
- **Advanced Insulation Materials (AIM):**
- **Vacuum Insulation Materials (VIM)**
- **Gas Insulation Materials (GIM)**
- **Nano Insulation Materials (NIM)**
- **Dynamic Insulation Materials (DIM)**

Vacuum Insulation Material (VIM)



VIM - A basically homogeneous material with a closed small pore structure filled with vacuum with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition

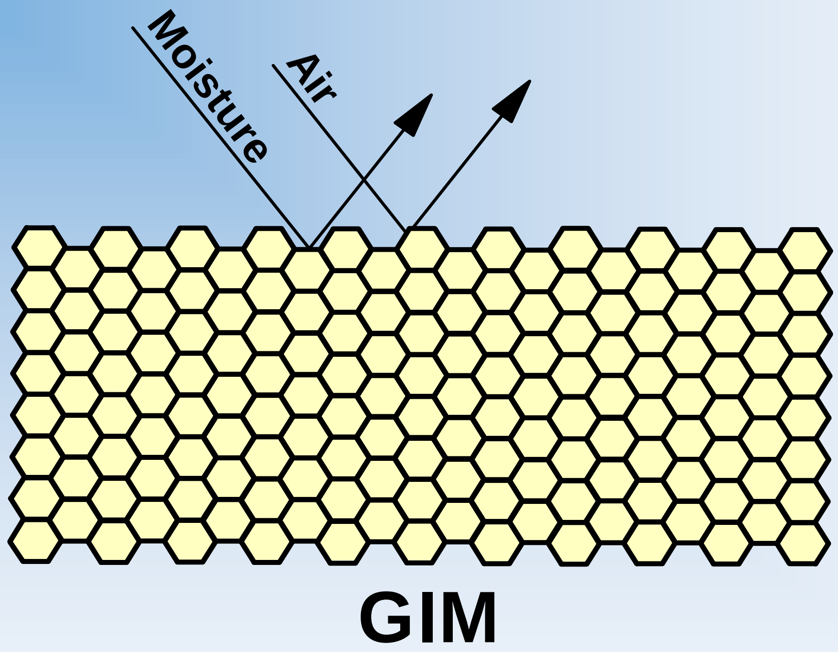
How to Make a VIM ?



A solid state material blowing itself up from within during the formation

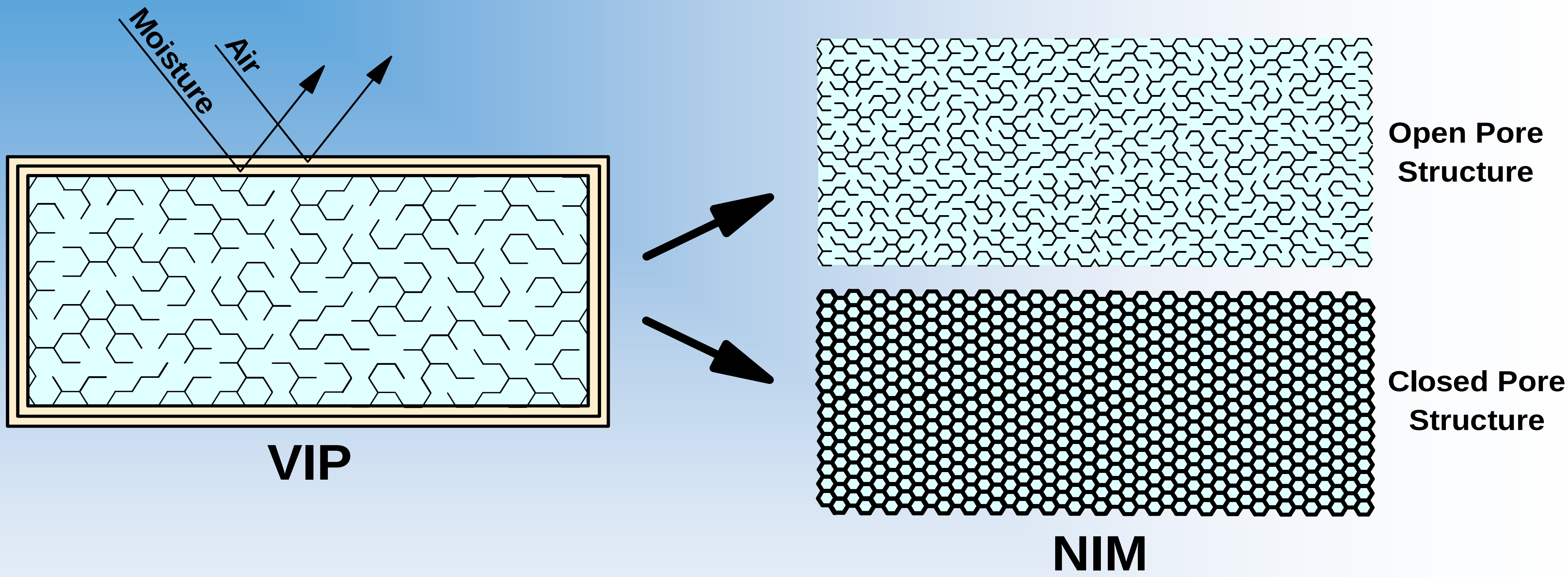
Gas Insulation Material (GIM)

… and analogously with VIM we may define GIM as follows:



GIM - A basically homogeneous material with a closed small pore structure filled with a low-conductance gas with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition

Nano Insulation Material (NIM)



NIM - A basically homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition

The Knudsen Effect – Nano Pores

Gas Thermal Conductivity λ_g

$$\lambda_g = \frac{\lambda_{g,0}}{1+2\beta Kn} = \frac{\lambda_{g,0}}{1+\dfrac{\sqrt{2}\beta k_B T}{\pi d^2 p\delta}}$$

$\sigma_{mean} > \delta$ $\Rightarrow$ low λ_g

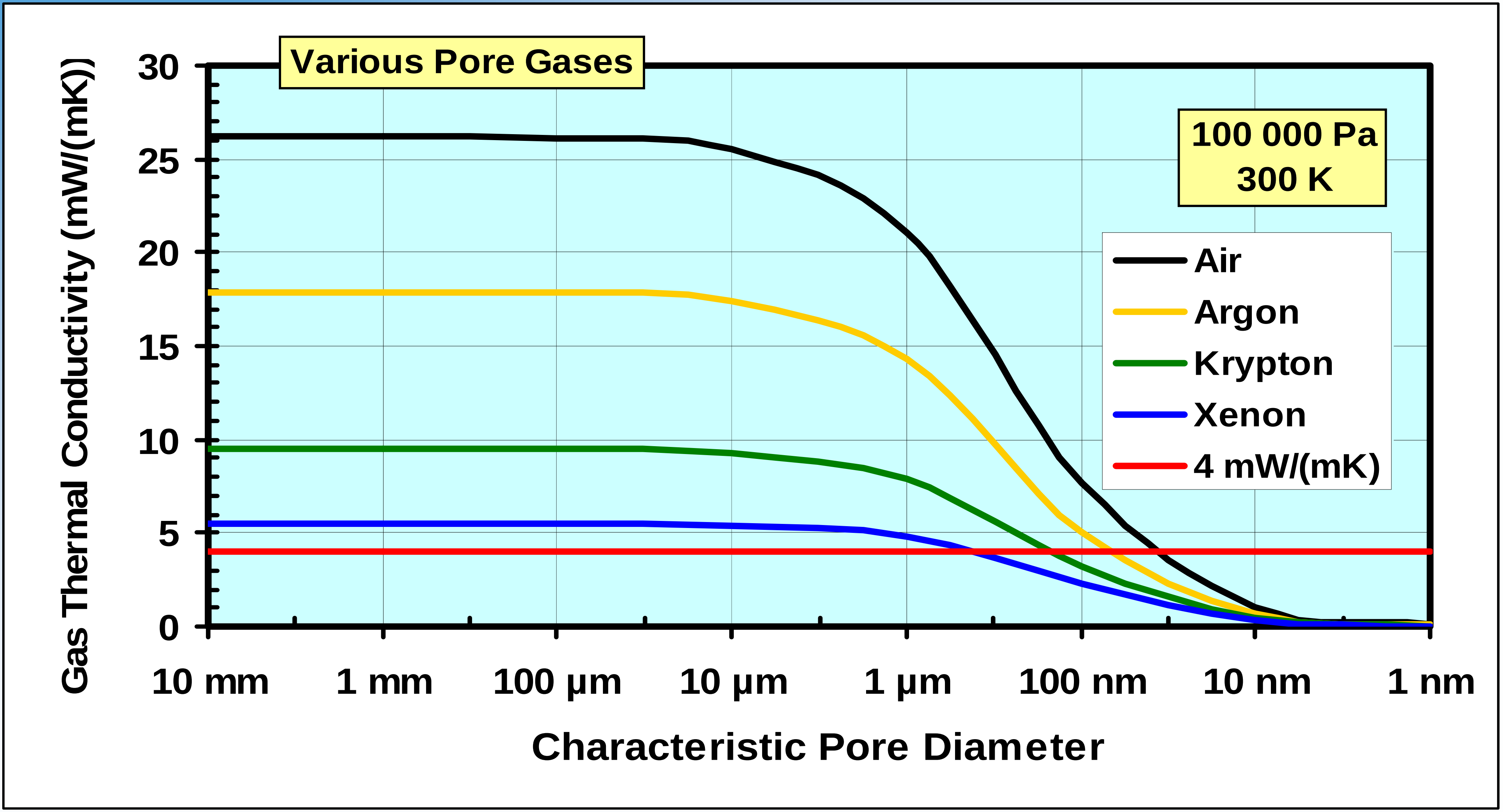
where

$$Kn = \frac{\sigma_{mean}}{\delta} = \frac{k_B T}{\sqrt{2}\pi d^2 p\delta}$$

λ_{gas} = gas thermal conductivity in the pores (W/(mK))
$\lambda_{gas,0}$ = gas thermal conductivity in the pores at STP (standard temperature and pressure) (W/(mK))
β = coefficient characterizing the molecule - wall collision energy transfer efficiency (between 1.5 - 2.0)
Kn = $\sigma_{mean}/\delta = k_BT/(2^{1/2}\pi d^2 p\delta)$ = the Knudsen number
k_B = Boltzmann's constant ≈ $1.38\cdot10^{-23}$ J/K
T = temperature (K)
d = gas molecule collision diameter (m)
p = gas pressure in pores (Pa)
δ = characteristic pore diameter (m)
σ_{mean} = mean free path of gas molecules (m)

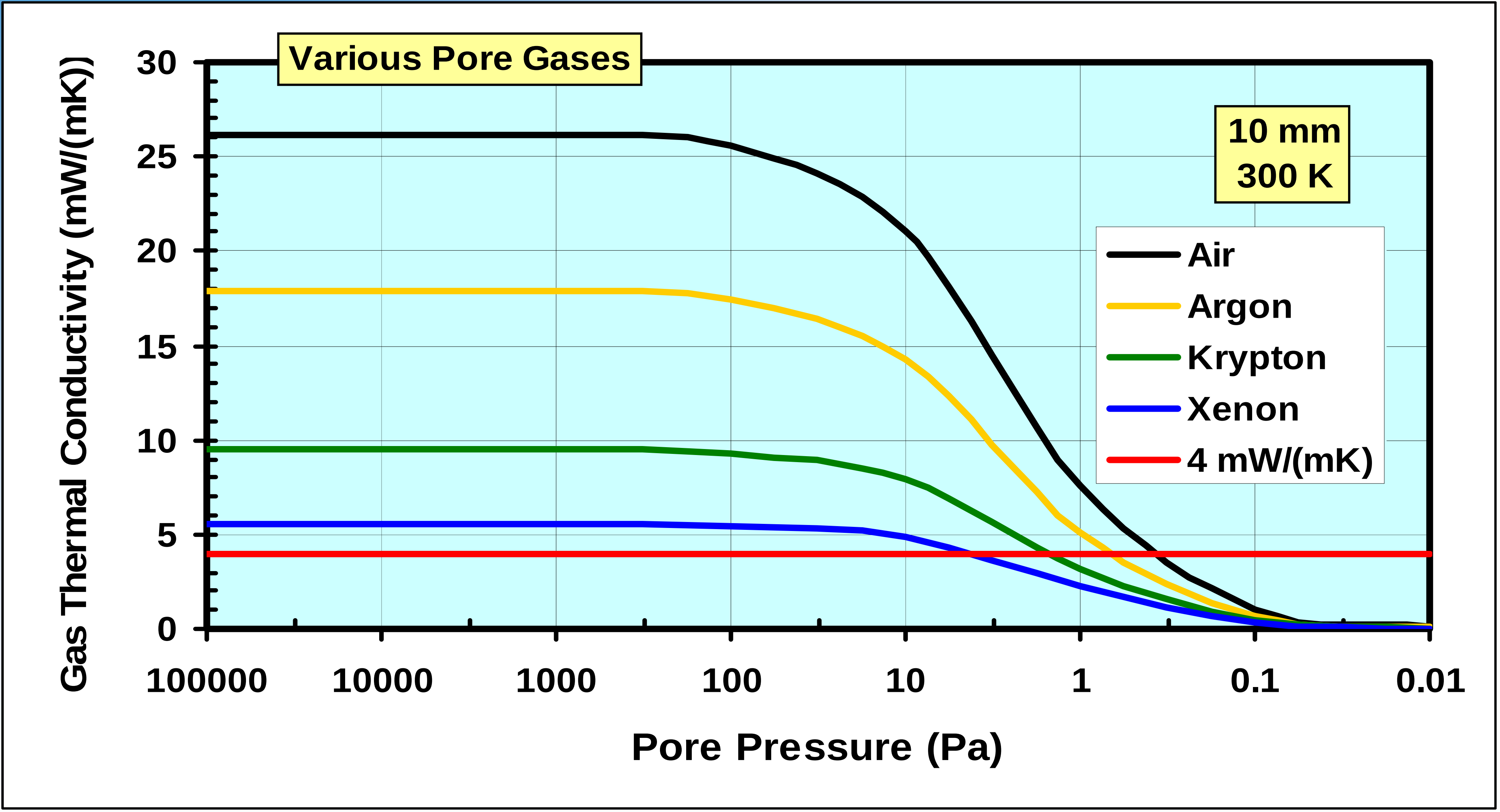
Gas Thermal Conductivity

Conductivity vs. Pore Diameter

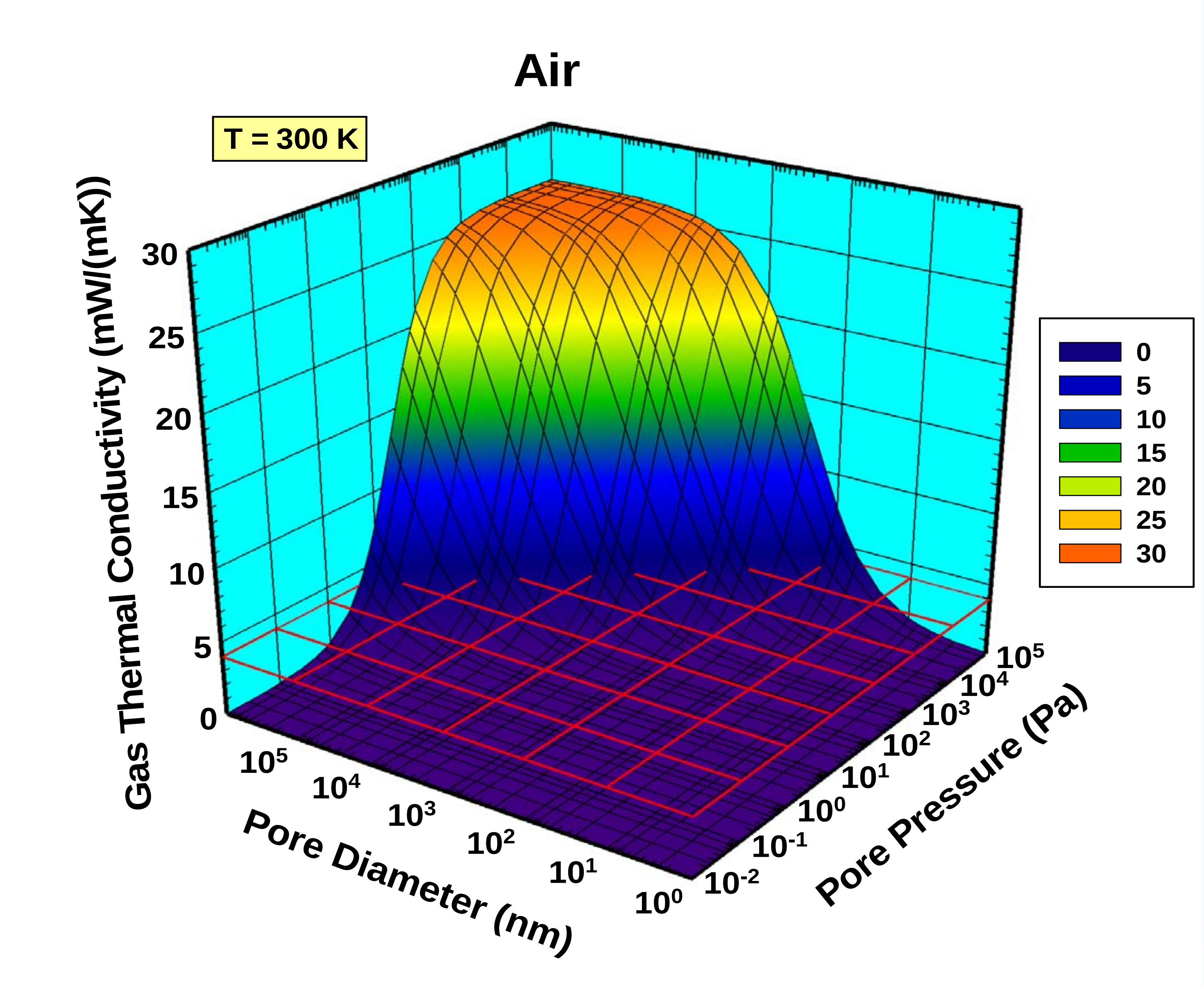


Gas Thermal Conductivity

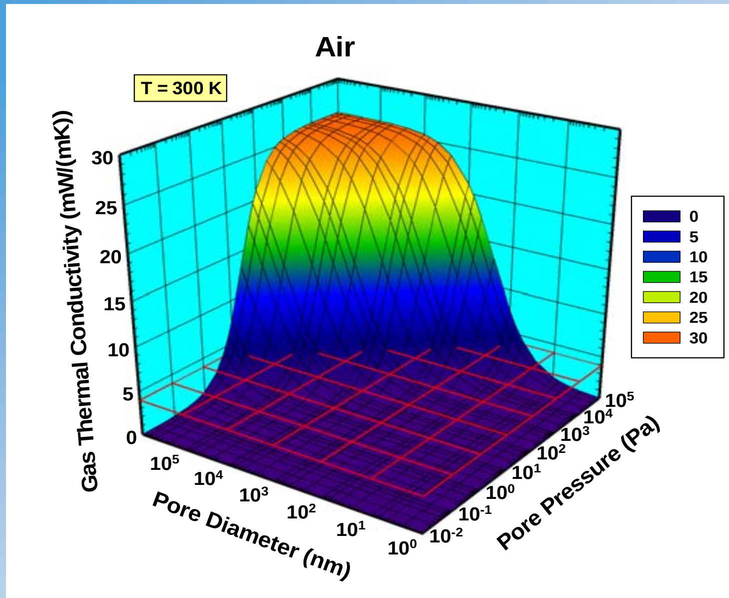
Conductivity vs. Pore Pressure

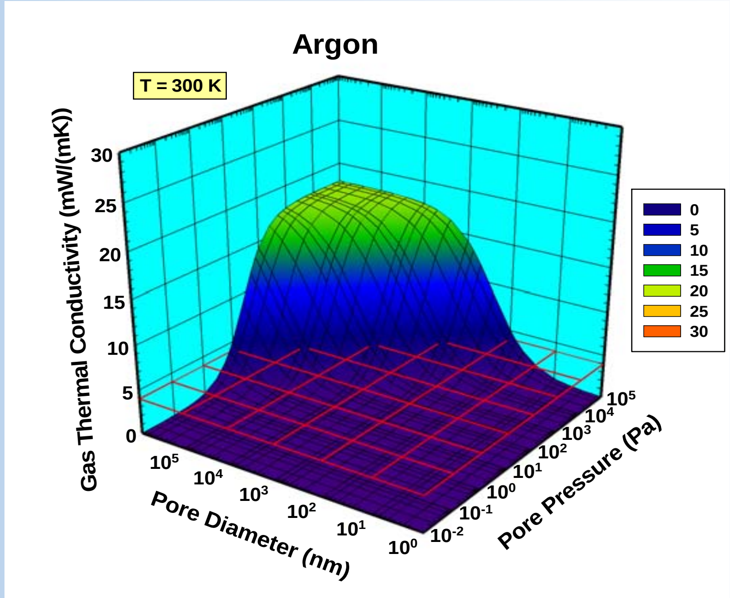


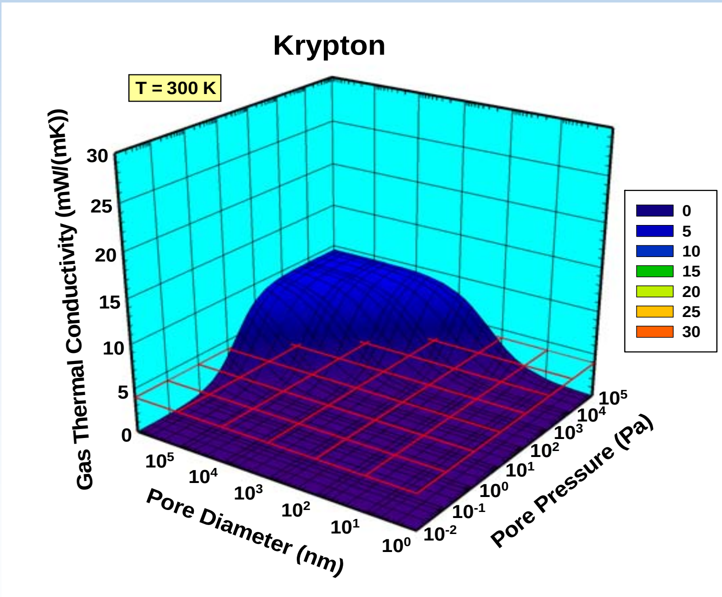
Gas Thermal Conductivity

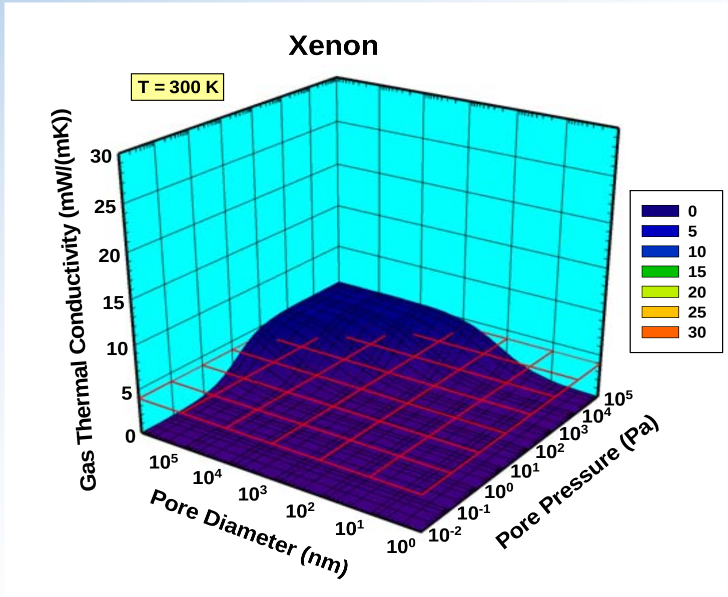


Gas Thermal Conductivity









Nano Pores – Thermal Radiation

- **Knudsen effect $\Rightarrow \sigma_{mean} > \delta \Rightarrow$ low gas thermal conductivity λ_g**
- **What about the thermal radiation in the pores?**
- **"Classical" – from Stefan-Boltzmann's law:**

$$\lambda_r = \frac{\pi^2 k_B^4 \delta}{60\hbar^3 c^2 \left[\frac{2}{\varepsilon} - 1\right]} \frac{(T_i^4 - T_e^4)}{(T_i - T_e)}$$

λ_r = thermal radiation conductivity in the pores (W/(mK))
σ = = $\pi^2 k_B^4/(60\hbar^3 c^2)$ = Stefan-Boltzmann's constant $\approx 5.67 \cdot 10^{-8}$ W/(m^{2}K^4)
k_B = Boltzmann's constant $\approx 1.38 \cdot 10^{-23}$ J/K
$\hbar = h/(2\pi) \approx 1.05 \cdot 10^{-34}$ Js (h = Planck's constant)
c = light velocity $\approx 3.00 \cdot 10^8$ m/s
δ = pore diameter (m)
ε = emissivity of pore walls
T_i = interior temperature (K)
T_e = exterior temperature (K)
ξ_{ir} = infrared radiation wavelength (m)

- **Pore diameter δ small $\Rightarrow$ low thermal radiation conductivity λ_r**
- **But what happens when $\xi_{ir} > \delta$? (IR wavelength > pore diameter)**
- **$\xi_{ir} > \delta \Rightarrow$ high thermal radiation conductivity λ_r ?**
- **Evanescent waves… tunneling… etc. …**
- **Currently looking into these matters…**

Thermal Radiation in Nano Pores

Total Radiation Heat Flux $J_{rad,tot}$

$$J_{rad,tot} = \frac{\sigma}{n\left[\frac{2}{\varepsilon} - 1\right]}(T_i^4 - T_e^4)$$

Stefan-Boltzmann's Law

$\lambda_{rad} = J_{rad,tot}\delta/(T_{k-1} - T_k)$ is found by applying the approximation $(T_{k-1} - T_k) = (T_i - T_e)/n$

Radiation Thermal Conductivity λ_{rad}

$$\lambda_{rad} = \frac{\sigma\delta}{\left[\frac{2}{\varepsilon} - 1\right]}\frac{(T_i^4 - T_e^4)}{(T_i - T_e)} = \frac{\pi^2 k_B^4 \delta}{60\hbar^3 c^2\left[\frac{2}{\varepsilon} - 1\right]}\frac{(T_i^4 - T_e^4)}{(T_i - T_e)}$$

Thermal Radiation in Nano Pores

Radiation Thermal Conductivity λ_{rad}

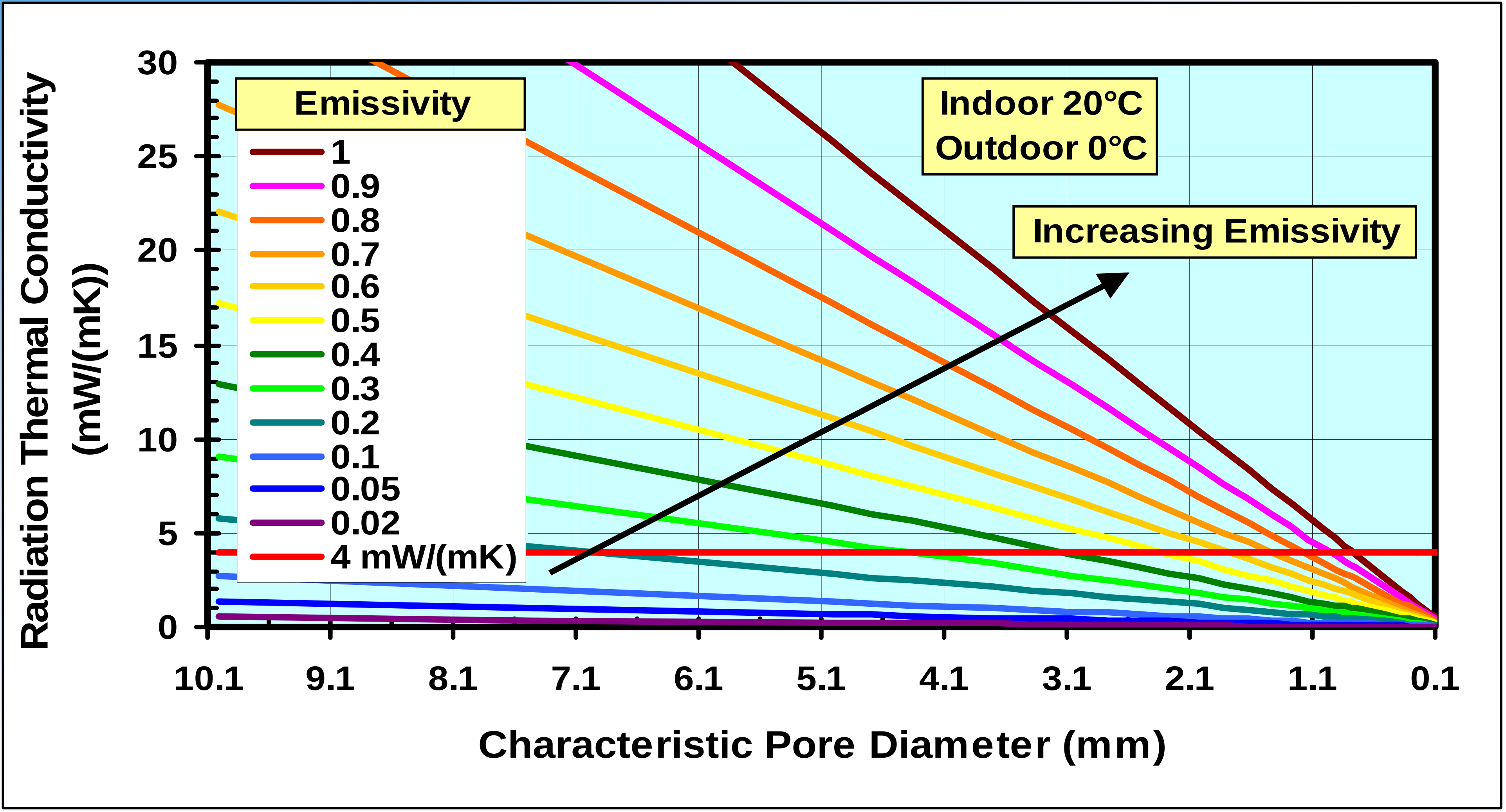
$$\lambda_{rad} = \frac{\sigma\delta}{\left[\frac{2}{\varepsilon}-1\right]}\frac{(T_i^4 - T_e^4)}{(T_i - T_e)} = \frac{\pi^2 k_B^4 \delta}{60\hbar^3 c^2\left[\frac{2}{\varepsilon}-1\right]}\frac{(T_i^4 - T_e^4)}{(T_i - T_e)}$$

$$J_{rad,tot} = \frac{\sigma}{n\left[\frac{2}{\varepsilon}-1\right]}(T_i^4 - T_e^4)$$

λ_{rad} = radiation thermal conductivity in the pores (W/(mK))
$\sigma = \pi^2 k_B^4/(60\hbar^3 c^2)$ = Stefan-Boltzmann's constant $\approx 5.67\cdot10^{-8}$ W/(m^{2}K^4)
k_B = Boltzmann's constant $\approx 1.38\cdot10^{-23}$ J/K
$\hbar = h/(2\pi) \approx 1.05\cdot10^{-34}$ Js = reduced Planck's constant (h = Planck's constant)
c = velocity of light $\approx 3.00\cdot10^{8}$ m/s
δ = pore diameter (m)
ε = emissivity of inner pore walls (assumed all identical)
T_i = interior (indoor) temperature (K)
T_e = exterior (outdoor) temperature (K)
$J_{rad,tot}$ = total radiation heat flux (W/m^2)
n = number of pores along a given horizontal line in the material

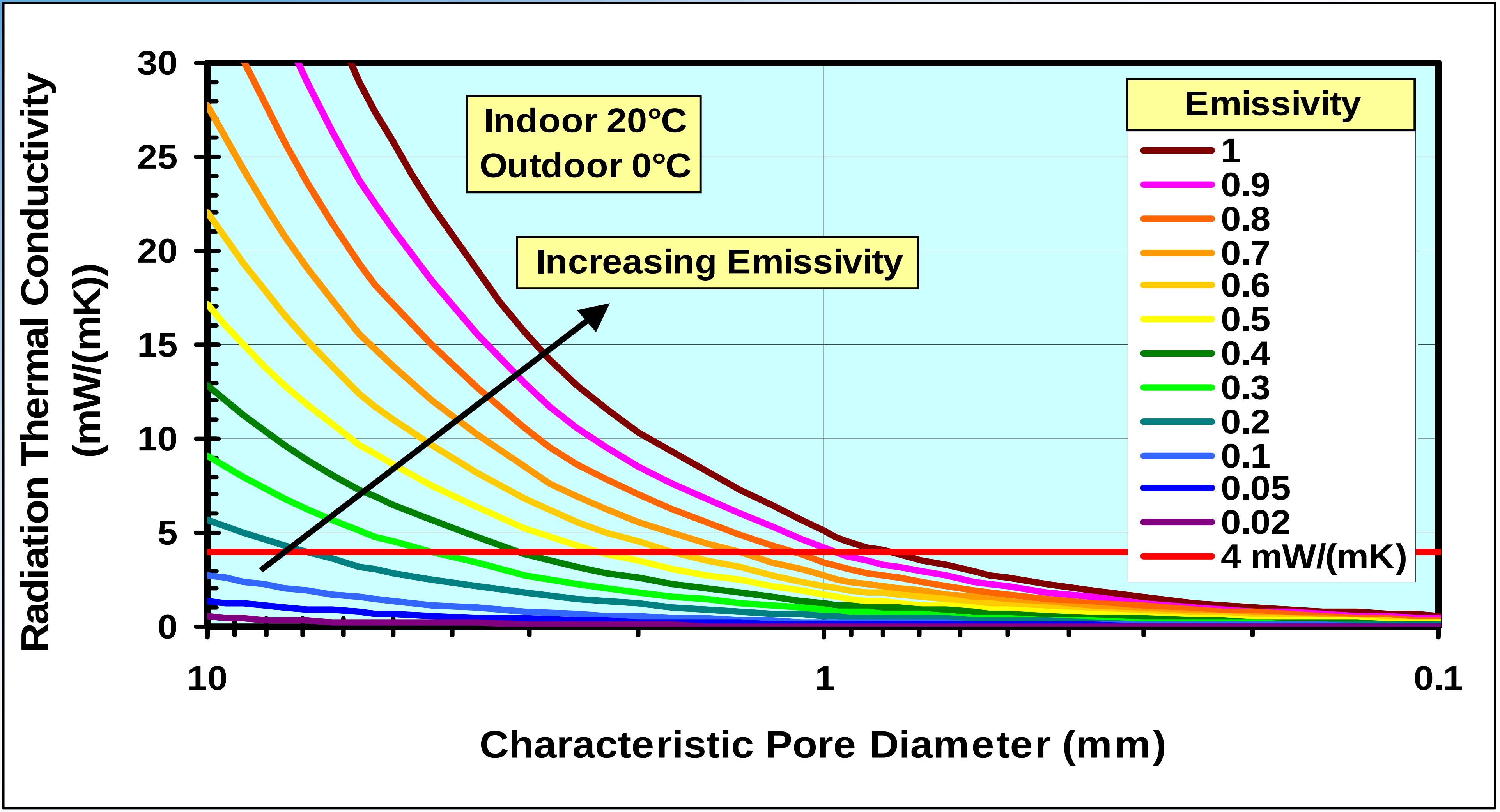
Radiation Thermal Conductivity

Conductivity vs. Pore Diameter



Radiation Thermal Conductivity

Conductivity vs. Pore Diameter

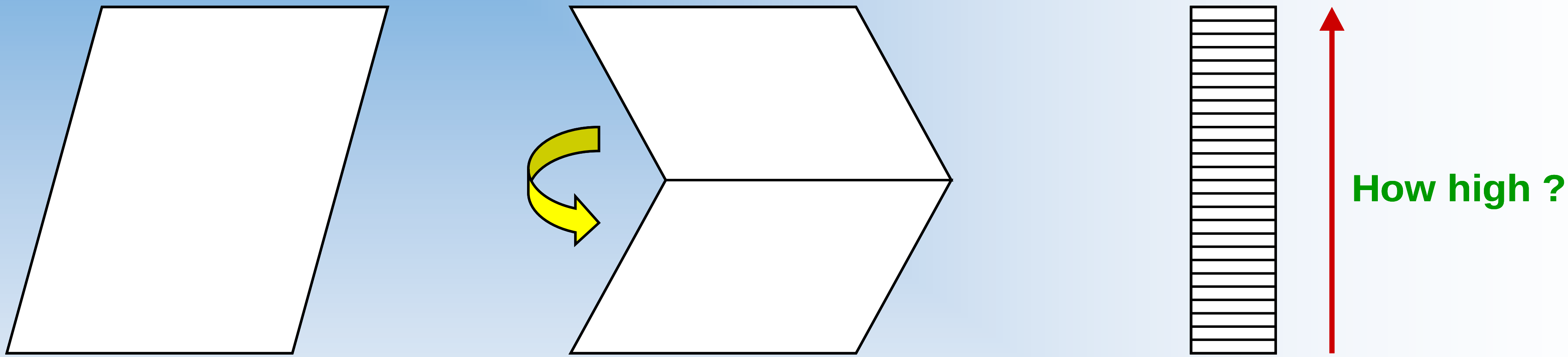


Radiation Thermal Conductivity

- Stefan-Boltzmann's law $\Rightarrow$ Linear λ_{rad} vs. δ relationship $\Rightarrow$
- Pore diameter δ small $\Rightarrow$ low radiation thermal conductivity λ_{rad}
- But what happens when $\xi_{ir} > \delta$? (IR wavelength > pore diameter)
- $\xi_{ir} > \delta \Rightarrow$ high radiation thermal conductivity λ_{rad} ?
- Tunneling of evanescent waves
- Indications that the large thermal radiation is only centered around a specific wavelength (or a few) $\Rightarrow$
- The total thermal radiation integrated over all wavelengths is not that large (?)
- Currently looking into these matters…

How Good are You at Guessing?

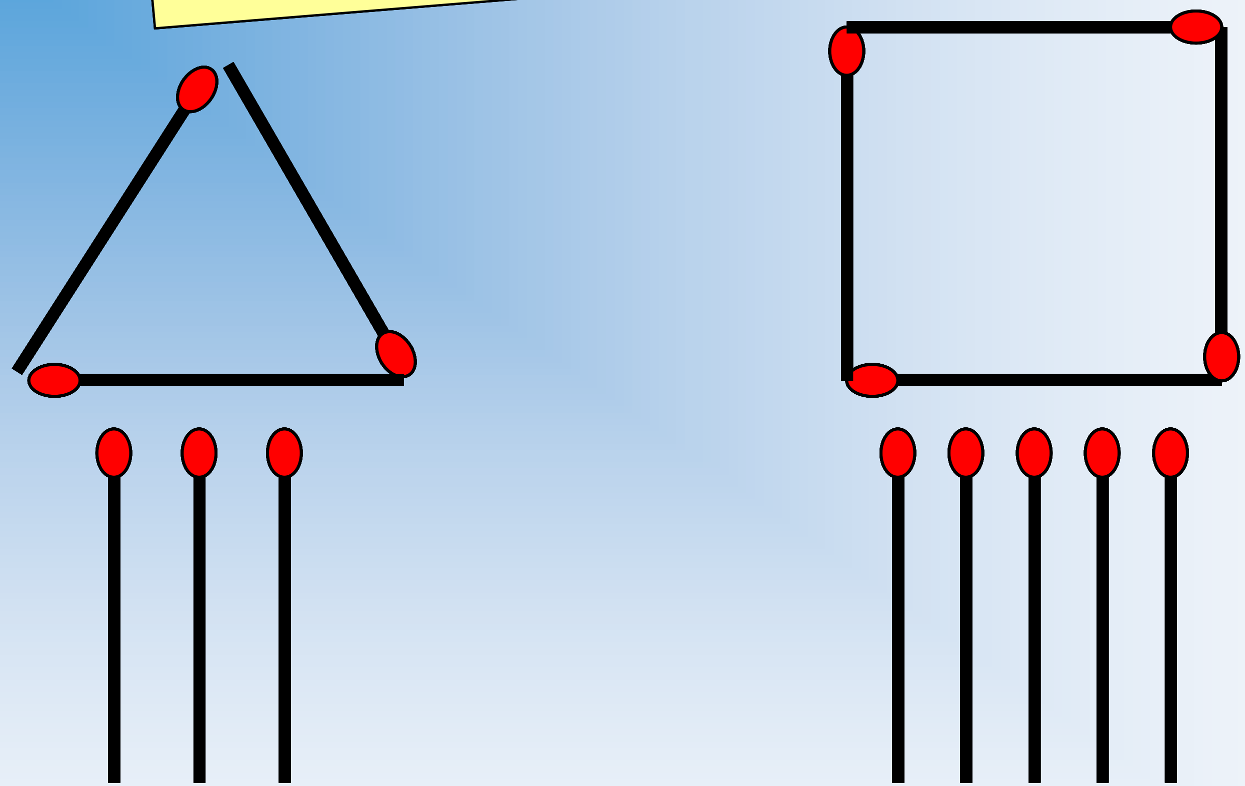
The A4 Paper Folding



- **Fold an A4 paper 100 times.**
- **Press out all air between the paper sheets.**
- **Put the paper pile on the table in front of you.**
- **Guess how far above the table does the paper pile reach ?**

Today's Second Nut

The Triangle and The Square



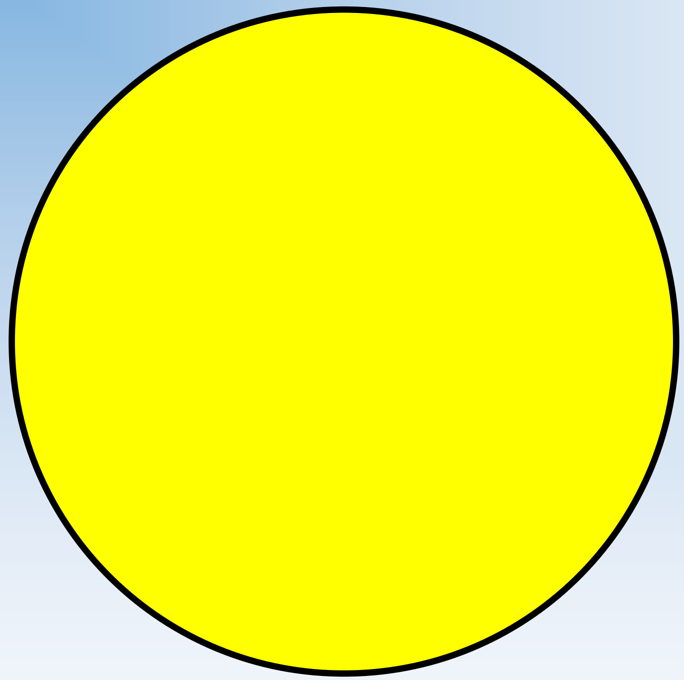
Triangle: **Make 4 identical equilateral triangles *as the one above* (same size also!) out of a total of 6 matches.**

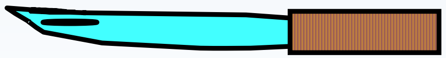
Square: **Make 6 identical squares *as the one above* (same size also!) out of a total of 9 matches.**

Today’s Third Nut

The Cake Division

The Cake Nut - A Nut Cake ?

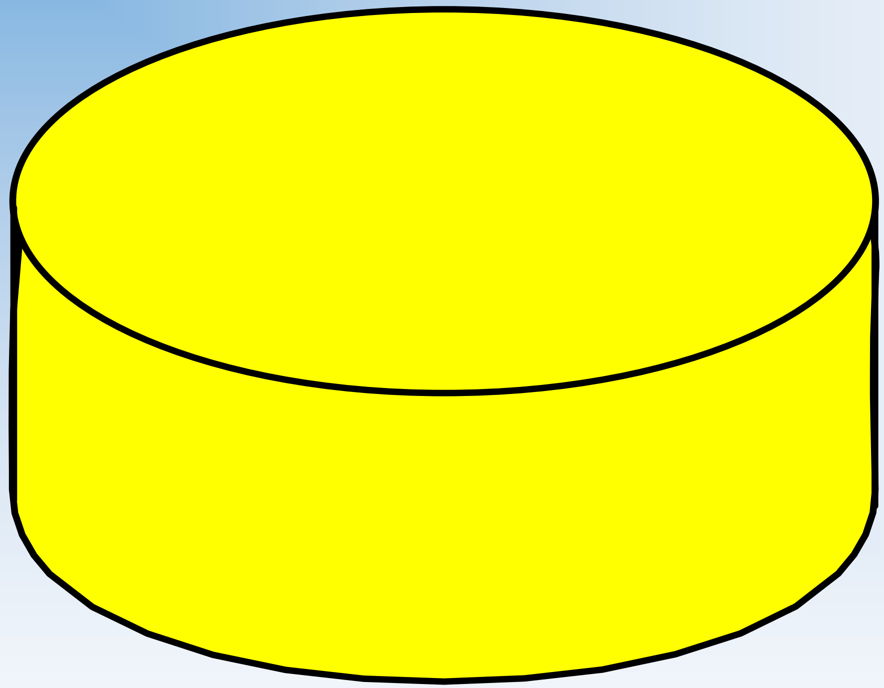


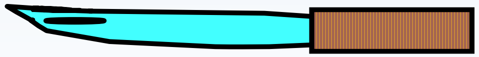
 **x 3 = 8 identical cake pieces**

Today's Third Nut

The Cake Division

The Cake Nut - A Nut Cake ?

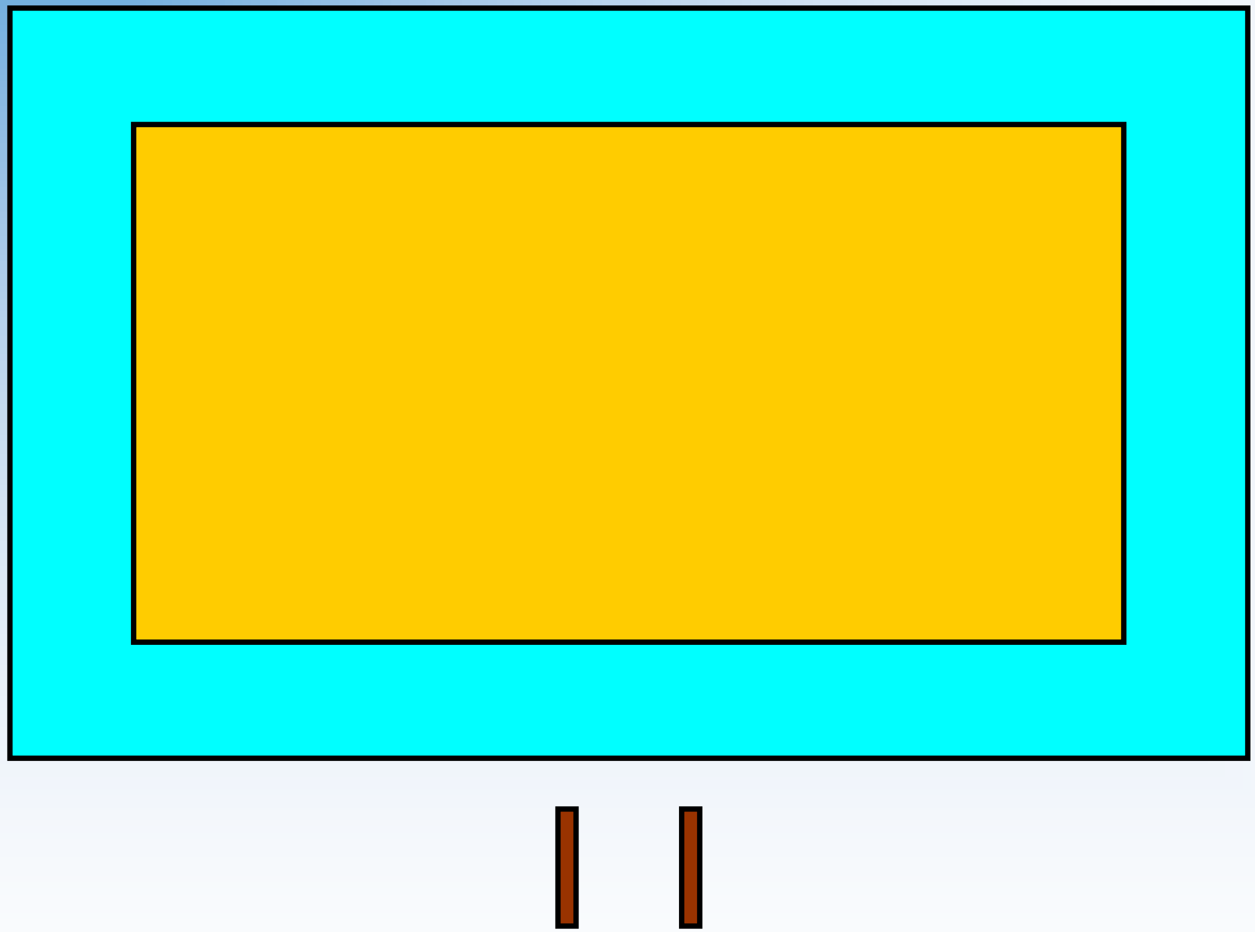


 **x 3 = 8 identical cake pieces**

Today's Fourth Nut

The Moat

Get over the moat in a safe way – each log is just too short !



Today's Fifth and Sixth Nut

The Hole

Digging a hole:

5 men digs 4 holes in 3 days.
How long time does one man use to dig half a hole ?

The Expression

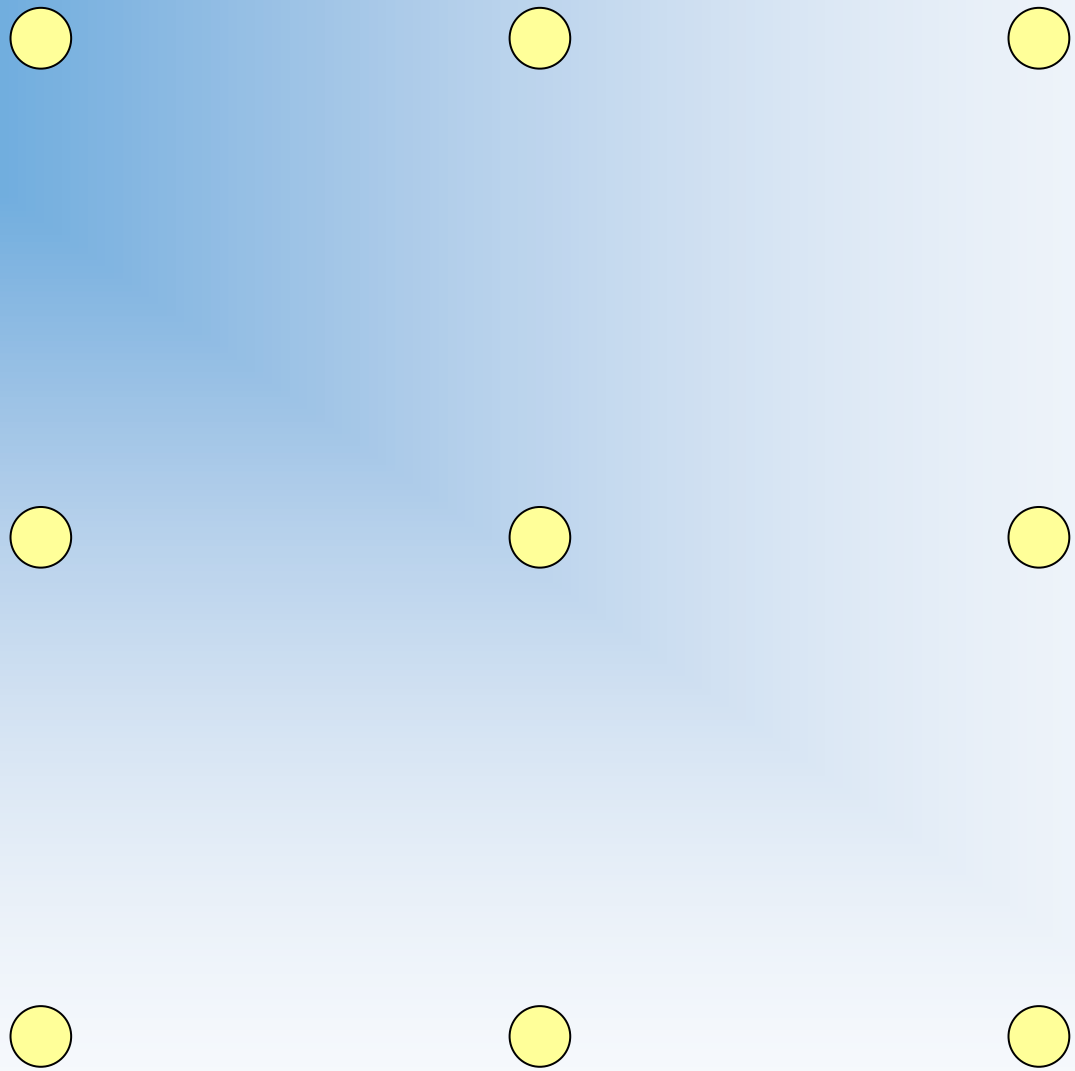
Solve the expression:

$$(x-a)(x-b)(x-c)\cdot\ldots\cdot(x-z) = ?$$

Today's Seventh Nut

The 9 Dots

Draw 4 straight lines without lifting the pencil where you are striking all the 9 dots in the figure.



Dynamic Insulation Material (DIM)

DIM – A material where the thermal conductivity can be controlled within a desirable range

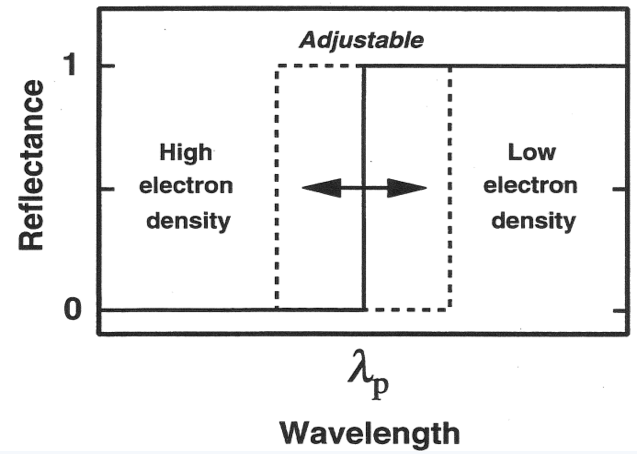
- **Thermal conductivity control may be achieved by:**
  - **Inner pore gas content or concentration including the mean free path of the gas molecules and the gas-surface interaction**
  - **The emissivity of the inner surfaces of the pores**
  - **The solid state thermal conductivity of the lattice**
- **What is really solid state thermal conductivity? Two models:**
  - **Phonon thermal conductivity - atom lattice vibrations**
  - **Free electron thermal conductivity**
- ***What kind of physical model could describe and explain thermal conductivity?***
- ***Could it be possible to dynamically change the thermal conductivity from very low to very high, i.e. making a DIM?***

Dynamic Insulation Material (DIM)

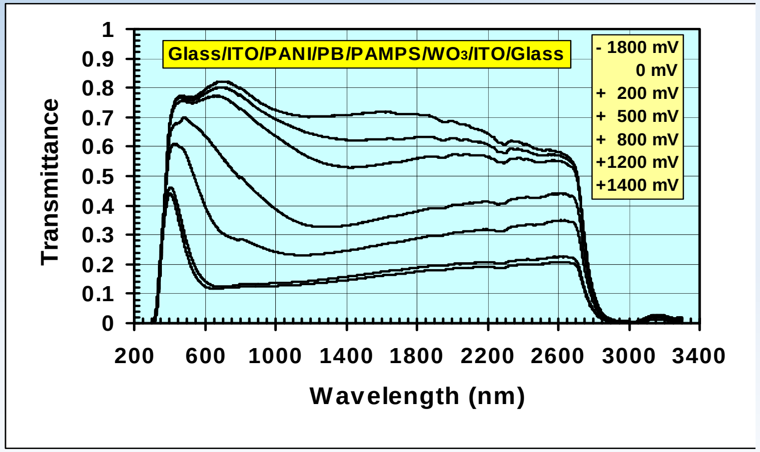
- **Dynamic Vacuum**
- **Dynamic Emissivity of Inner Pore Surfaces**
- **Dynamic Solid Core Thermal Conductivity**
  - Is it possible?
  - Fundamental understanding of the thermal conductance?
- **Other?**

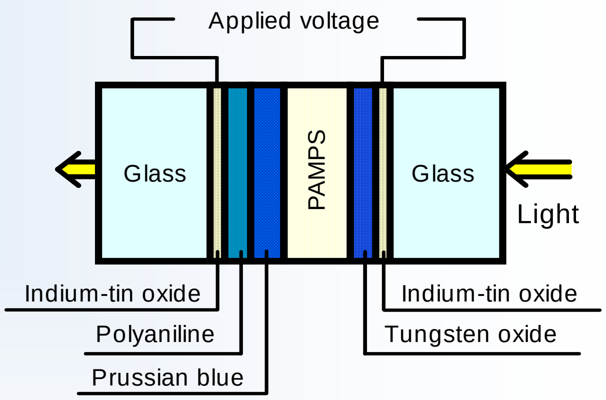
Learning from Electrochromic Materials?:

$$\lambda_p = (2\pi c/q_e)(m_e\varepsilon_0/n_e)^{1/2}$$



B. P. Jelle, "Electrochemical and Spectroscopic Studies of Electrochromic Materials", *Ph.D. thesis*, 1993:131, Department of Applied Electrochemistry, The Norwegian Institute of Technology, Trondheim, Norway, 1993.





B. P. Jelle, A. Gustavsen, T.-N. Nilsen and T. Jacobsen, "Solar Material Protection Factor (SMPF) and Solar Skin Protection Factor (SSPF) for Window Panes and other Glass Structures in Buildings", *Solar Energy Materials & Solar Cells*, 91, 342-354 (2007).

Inspiration and Ideas

Could other fields of science and technology inspire and give ideas about how to be able to make DIMs, e.g. from the fields?:

- **Electrochromic Materials**
- **Quantum Mechanics**
- **Electrical Superconductivity**
- **Other?**

Example of Application of Nano Technology with Concrete

Concrete Research And Development

Concrete research looks for materials and processes to:

- reduce material costs and energy costs
- obtain high initial and final resistance
- improve density and compressive strength
- improve workability, pumpability and finishability
- improve durability and reduce permeability
- reduce shrinkage cracks, dusting and delamination problems
- chemical resistance, e.g. sulfate resistance

… by the way…

What research and property of concrete is "missing" here?

… yes, exactly…:

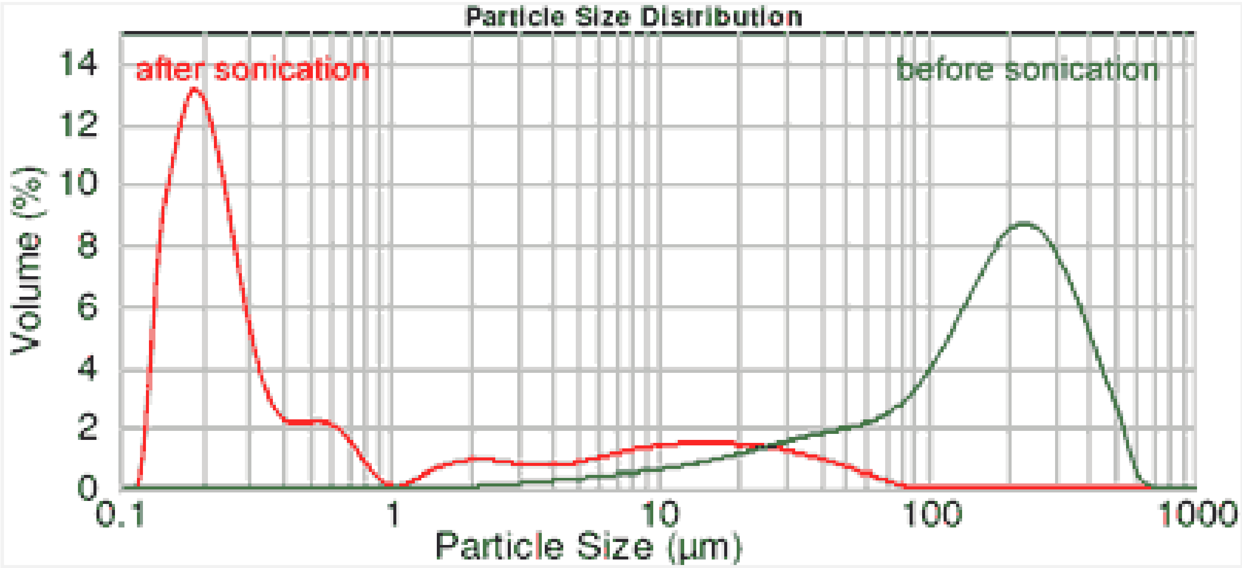
- **Thermal performance, e.g. thermal conductivity.**

http://www.hielscher.com/ultrasonics/nano_cement_concrete_01.htm

Example of Application of Nano Technology with Concrete

Ultrasonic Mixing Of Nanomaterials

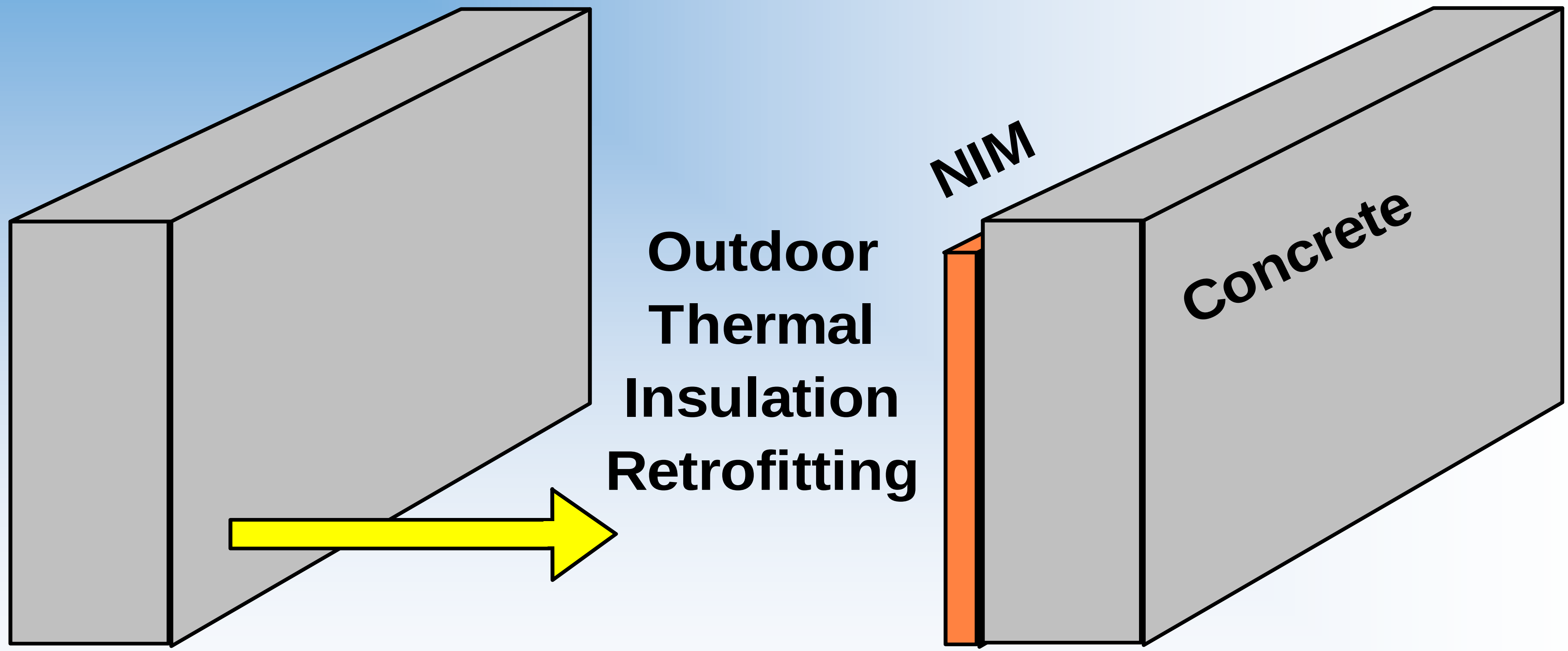
Ultrasonication is a very effective means for the mixing, dispersing and deagglomeration. The picture below shows a typical result of ultrasonic dispersing of fumed silica in water.



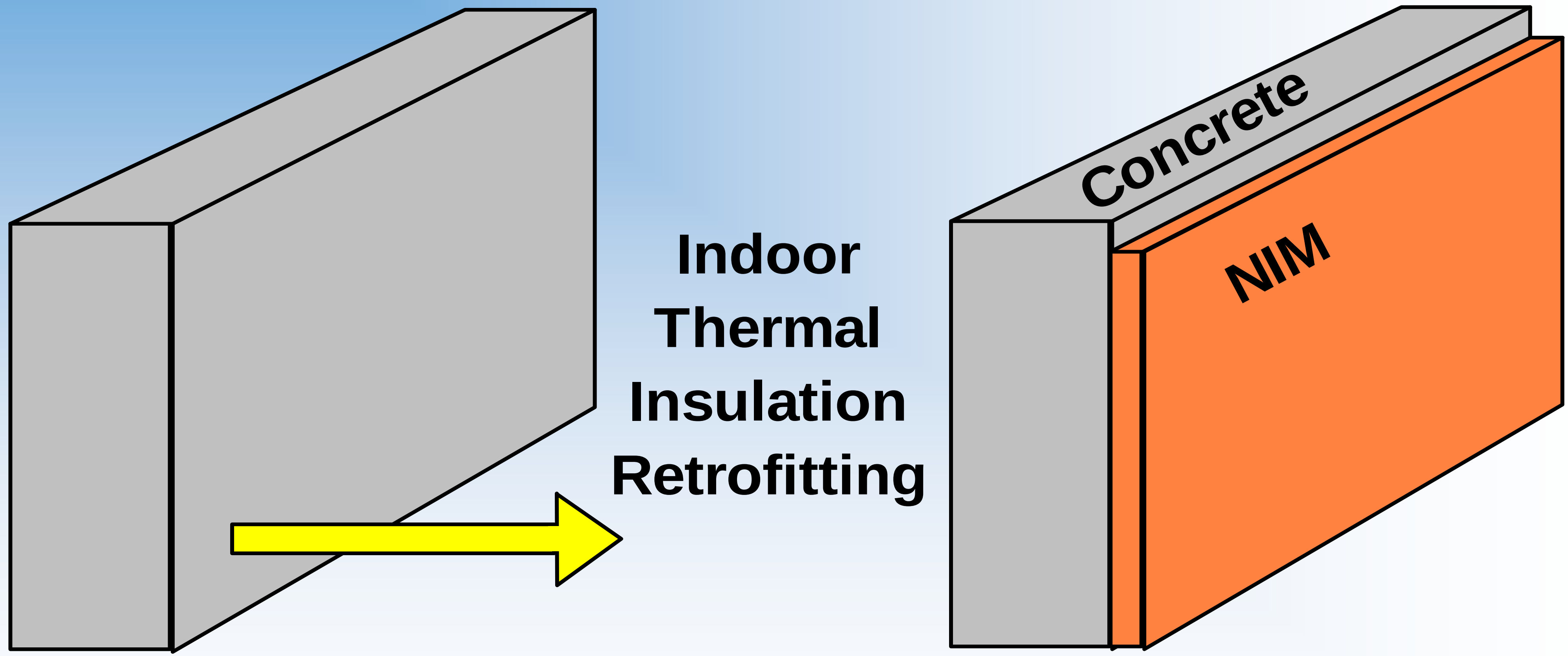
Starting (green curve) at an agglomerate particle size of more than 200 micron (D50) most of the particles were reduced to less than 200 nanometers.

http://www.hielscher.com/ultrasonics/nano_cement_concrete_01.htm

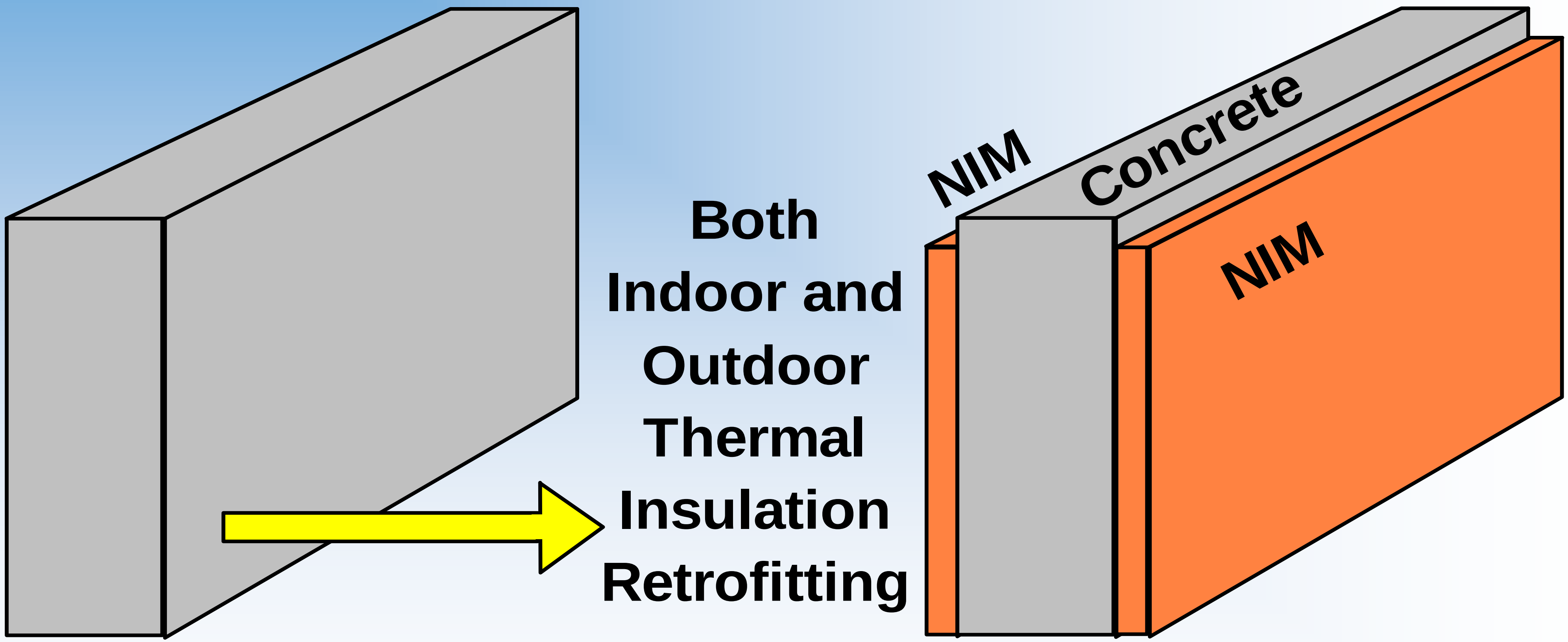
Concrete with NIM Outdoor Retrofitting



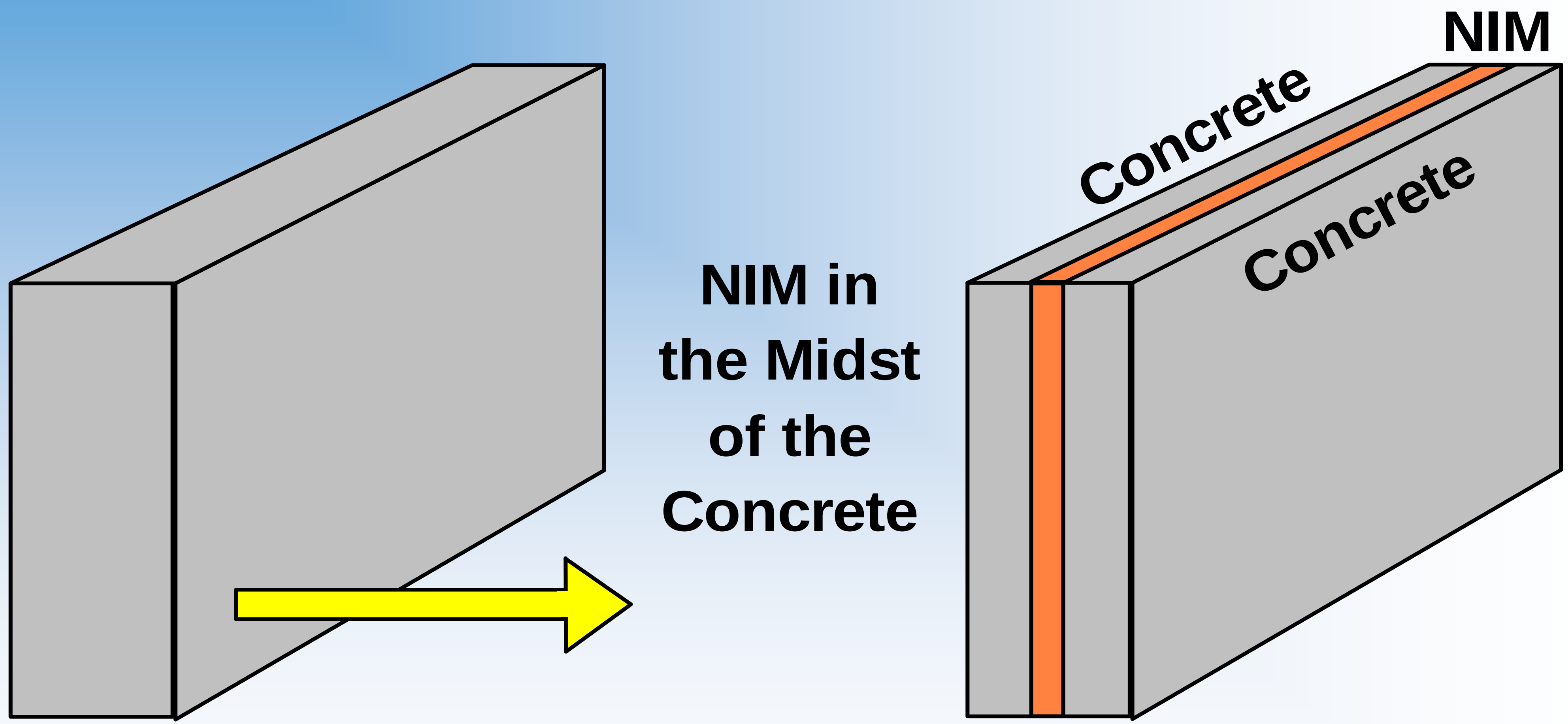
Concrete with NIM Indoor Retrofitting



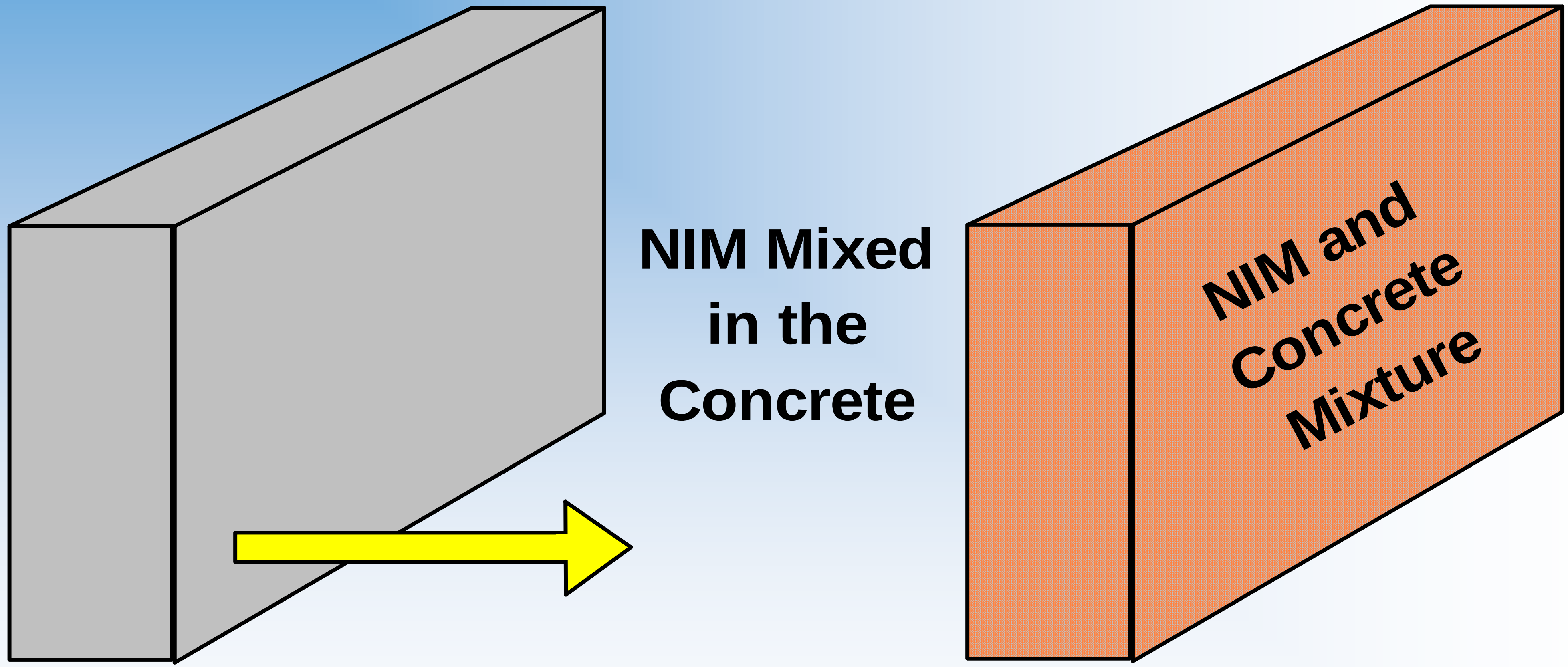
Concrete with NIM Indoor and Outdoor



NIM in the Midst of Concrete

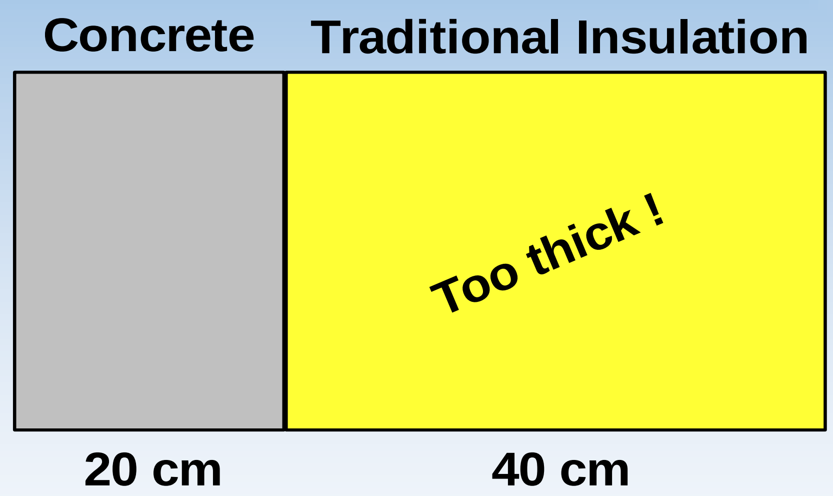


NIM and Concrete Mixture

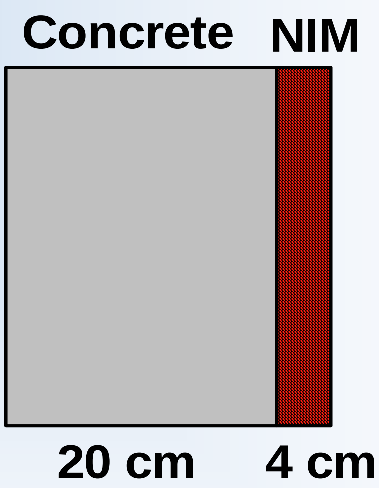


Thinner Concrete Buildings with NIMs

- Mineral Wool or Polystyrene
- 36 mW/(mK)
- 40 cm traditional thermal insulation retrofitting



- NIM
- 3.6 mW/(mK)
- 4 cm NIM thermal insulation



- A vast reduction – factor 10 – of the thermal insulation layer and thereby the total building envelope thickness.

Aerogels – Approaching the NIMs

- Aerogels – At the moment the closest commercial approach to NIMs
- 12 – 14 mW/(mK)
- Aspen Aerogels
  - Spaceloft
- Cabot Aerogel
  - Nanogel

- Production costs still high
- Relatively high compression strength
- Very fragile due to very low tensile strength
- Tensile strength may be increased by incorporation of a carbon fibre matrix
- May be produced as either opaque, translucent or transparent materials
  - ➔ Thus enabling a wide range of possible building applications

To Envision Beyond Concrete ?

- ***In the community of concrete it might be compared to using profane language in the church and close to blasphemy to suggest that maybe the answer is not concrete after all…*** 👍☺

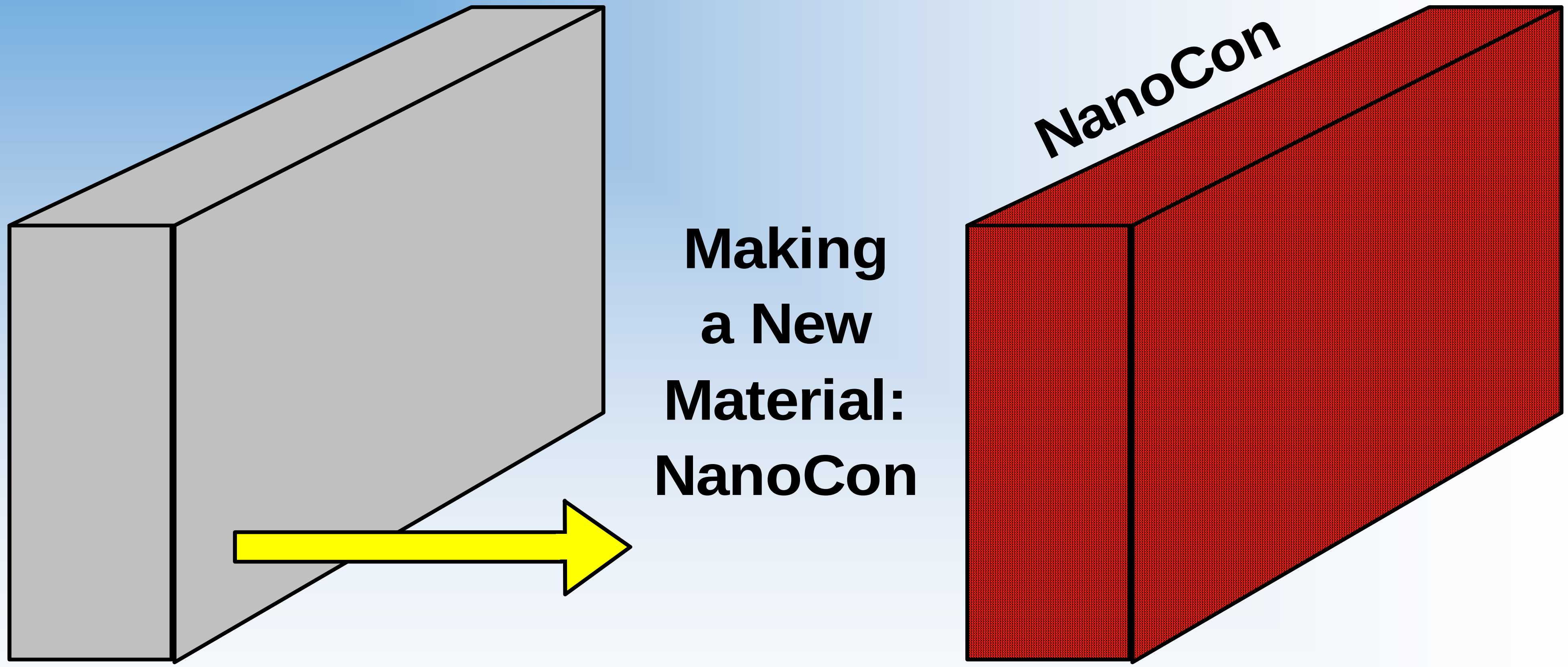
- **Concrete:**
- **High thermal conductivity.**
- **Total thickness of the building envelope will often become unnecessary large (passive house, zero energy building or zero emission building).**
- **Large CO_2 emissions connected to the production of cement.**
- **Prone to cracking induced by corrosion of the reinforcement steel.**
- **Easy accessible and workable, low cost and local production.**
- **High fire resistance.**

- **Is it possible to envision a building and infrastructure industry without an extensive usage of concrete?**

Emphasis on Functional Requirements

- Not the building material itself which is important.
- Property or functional requirements are crucial.
- Possible to invent and manufacture a material with the essential structural or construction properties of concrete intact or better, but with substantially lower thermal conductivity?
- Beneficial with a much lower negative environmental impact than concrete with respect to CO_2 emissions.
- Envisioned with or without reinforcement or rebars.

NanoCon – Introducing a New Material



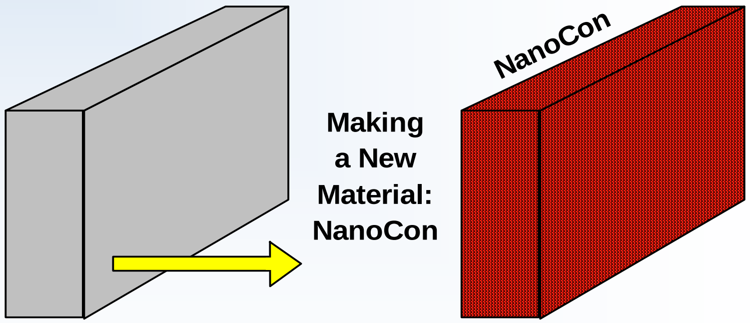
Making a New Material: NanoCon

NanoCon – Introducing a New Material

- **Defining a new material on a conceptual basis:**

- ***NanoCon* is basically a homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) (or another low value to be determined) and exhibits the crucial construction properties that are as good as or better than concrete.**

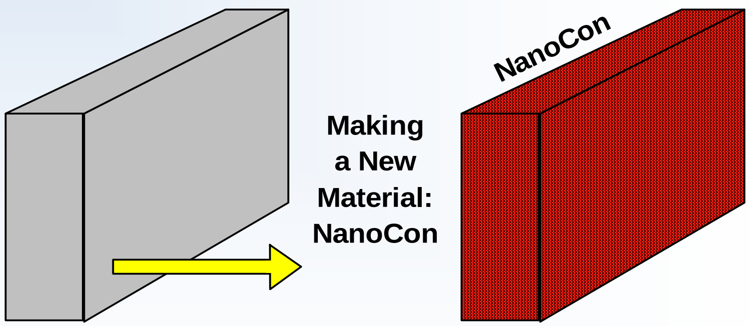
- **Note that the term "Con" in NanoCon is meant to illustrate the *construction* properties and abilities of this material, with historical homage to concrete.**



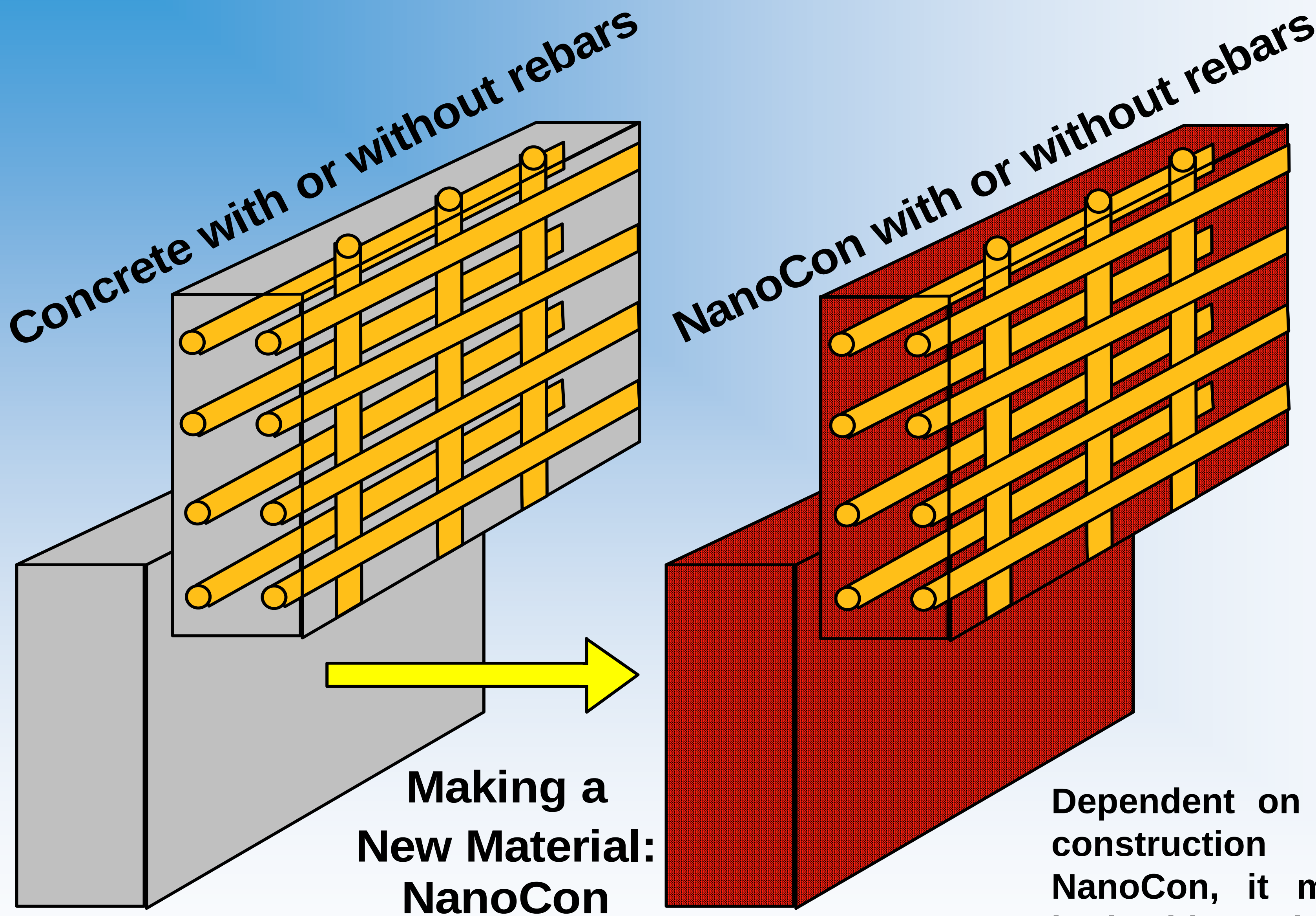
NanoCon – Introducing a New Material

- NanoCon
- Homogeneous material
- Closed or open small nano pore structure
- Overall thermal conductivity < 4 mW/(mK) (or another low value to be determined)
- Exhibits the crucial construction properties that are as good as or better than concrete.

- Essentially, NanoCon is a NIM with construction properties matching or surpassing those of concrete.



NanoCon – Introducing a New Material



Dependent on the mechanical or construction properties of NanoCon, it may be envisioned both with or without rebars.

Materials and Solutions Not Yet Thought Of ?

- ***The more we know the more we know we don't know…!***
  - ***… and the more we want to know…!***
  - ***… and that's the whole fun of it…!***
- ***Think thoughts not yet thought of…!***

The Thermal Insulation Potential

Thermal Insulation Materials and Solutions	Low Pristine Thermal Conductivity	Low Long-Term Thermal Conductivity	Perforation Robustness	Possible Building Site Adaption Cutting	Load-Bearing Capabilities	A Thermal Insulation Material and Solution of Tomorrow ?
Traditional						
Mineral Wool and Polystyrene	**no**	**no**	**yes**	**yes**	**no**	**no**
Todays State-of-the-Art						
Vacuum Insulation Panels (VIP)	**yes**	**maybe**	**no**	**no**	**no**	**today and near future**
Gas-Filled Panels (GFP)	**maybe**	**maybe**	**no**	**no**	**no**	**probably not**
Aerogels	**maybe**	**maybe**	**yes**	**yes**	**no**	**maybe**
Phase Change Materials (PCM)	**-**	**-**	**-**	**-**	**no**	**heat storage and release**
Beyond State-of-the-Art – Advanced Insulation Materials (AIM)						
Vacuum Insulation Materials (VIM)	**yes**	**maybe**	**yes**	**yes**	**no/maybe**	**yes**
Gas Insulation Materials (GIM)	**yes**	**maybe**	**yes**	**yes**	**no/maybe**	**maybe**
Nano Insulation Materials (NIM)	**yes**	**yes**	**yes, excellent**	**yes, excellent**	**no/maybe**	**yes, excellent**
Dynamic Insulation Materials (DIM)	**maybe**	**maybe**	**not known**	**not known**	**no/maybe**	**yes, excellent**
NanoCon	**yes**	**yes**	**yes**	**yes**	**yes**	**yes, excellent**
Others ?	**-**	**-**	**-**	**-**	**-**	**maybe**

Conclusions

- Several possibilities of applying nano technology and nano insulation materials (NIM) in order to improve the thermal performance of the future concrete buildings have been presented.
- NanoCon as essentially a NIM with construction properties matching or surpassing those of concrete has been introduced and defined.

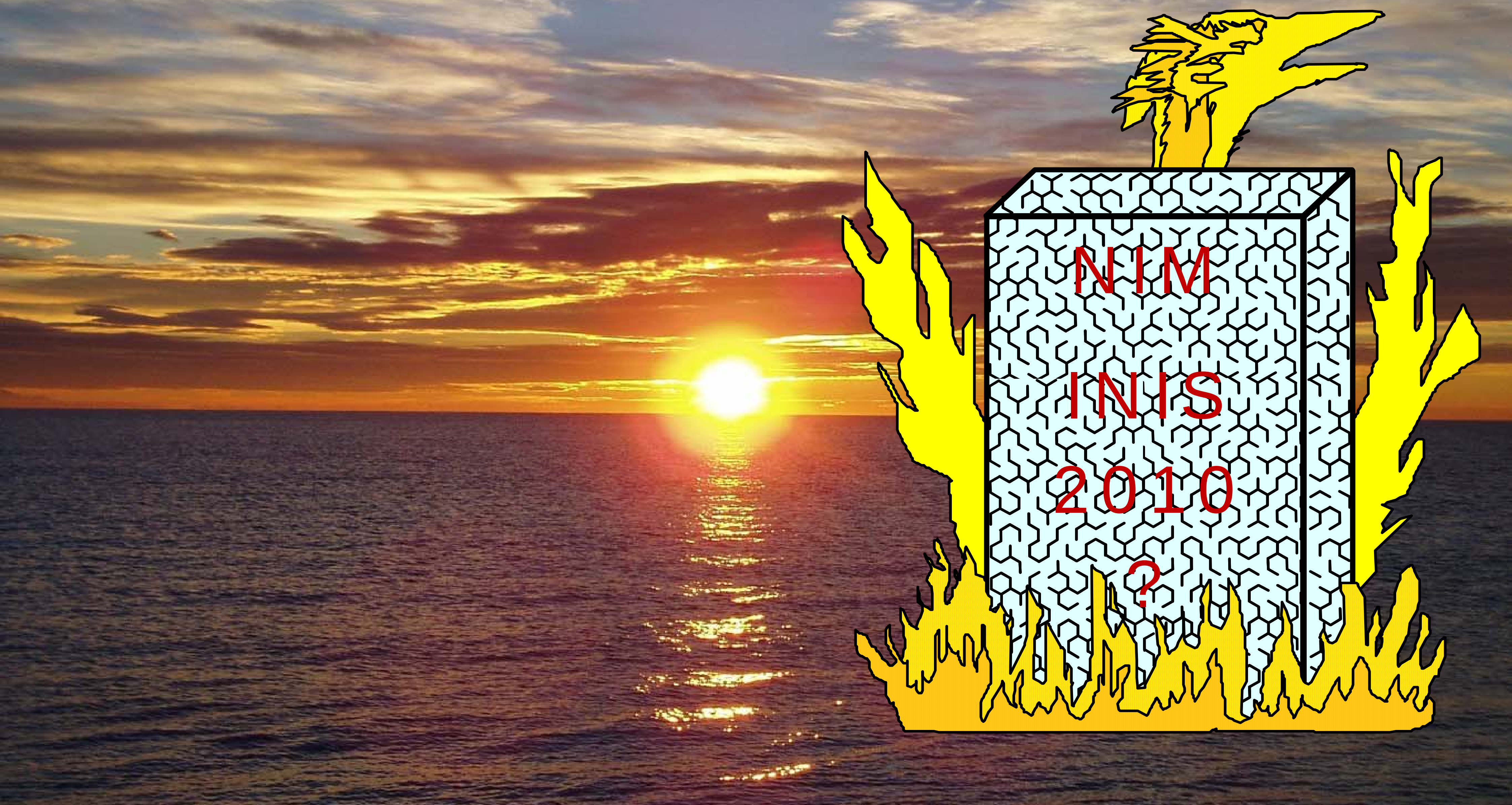
Sorry folks…
… we simply couldn't resist the two following slides…(!)

Analogously to the VIP-NIM originally presented at the 9th International Vacuum Insulation Symposium, London, September 17-18, 2009.

… though… with Concrete and NanoCon it might take several years…(!)

Sunset...

Sunrise…
and the Phoenix rises again…!



Sunset...

Sunrise...
and the Phoenix rises again...!