# Green Technologies for Sustainable Environment: CFR Research Overview

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And

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Einstein Professor of Chinese Academy of Sciences

CFR

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# Outline

- Research Goals
- Particle Technology Laboratory (PTL)
- Center for Filtration Research (CFR)
- CFR Basic Research
- CFR Innovative Applied Research
  - Gasoline Particulate Filter (GPF)
  - Solar Assisted Large Scale Cleaning System (SALSCS) for $PM_{2.5}$ Mitigation
  - SALSCS (2nd Gen) for $CO_2$ Reduction
  - SALSCS (3rd Gen) for Green Community

# Lancet Commissions

*"Pollution is the largest environmental cause of disease and premature death in the world today. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide— three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence. In the most severely affected countries, pollution-related disease is responsible for more than one death in four".*

**Lancet 2018; 391:462-512**

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# Research Goals

Our Goals are to develop **Green Technologies** that benefit **Sustainable Environment** which will enable people and the environment to prosper together, through:

1. Mitigate $PM_{2.5}$ in urban environment;
2. Reduce $CO_2$ to mitigate global climate change;
3. Clean water to achieve water sustainability.

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# Instrumentation Development at the Particle Technology Laboratory (PTL)




Chen, Pui, et al. *J. Aerosol Sci.* 29:497 (1998)

Fissan, Pui, et al. *J. Nanoparticle Res.* 9:53 (2007)

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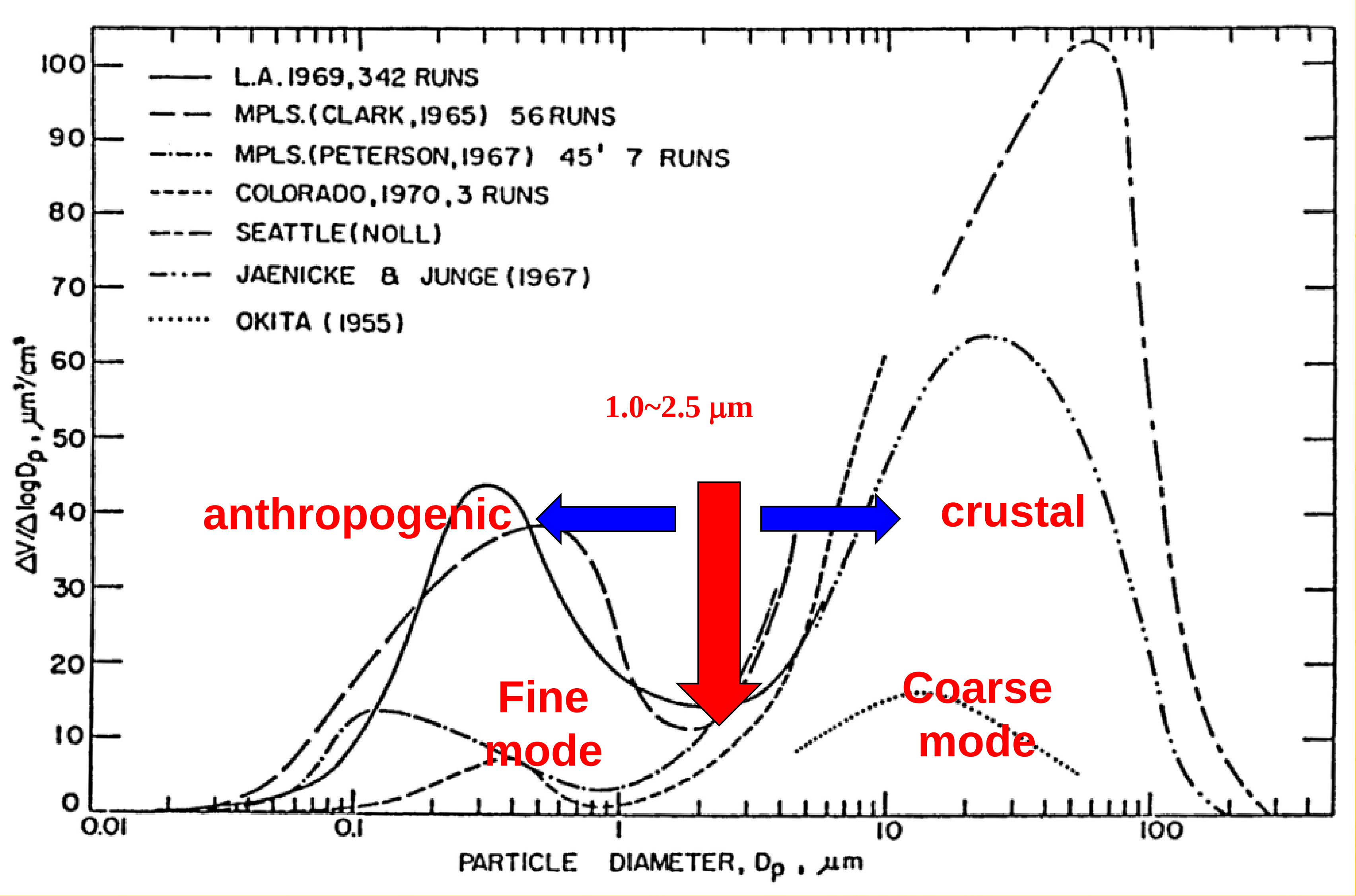
# Particle Size Distributions of Atmospheric Aerosols




Whitby, K. T., Husar, R. B., & Liu, B. Y. H. (1972) *Journal of Colloid and Interface Science*, *39*(1), 177-204..

# $PM_{2.5}$ Sources and Lifetimes

**Fine Particles**

*Combustion, gases to particles*

- Sulfates/acids
- Nitrate
- Ammonium
- Organics
- Carbon
- Metals
- Water

Sources:

- Coal, oil, gasoline, diesel, wood combustion
- Transformation of SOx, NOx, organic gases
- High-temperature industrial processes (smelters, steel mills)
- Forest fires

Exposure/Lifetime:

Lifetime days to weeks, regional distribution over urban scale to 1000s of km

**Inhalable Coarse Particles**

*Crushing, grinding, dust*

- Resuspended dusts (soil, street dust)
- Coal/oil fly ash
- Aluminum, silica, iron-oxides
- Tire and brake wear
- Inhalable biological materials, such as soils & plant fragments

Sources:

- Resuspension of dust tracked onto roads
- Suspension from disturbed soil (farms, mines, unpaved roads)
- Construction/demolition
- Industrial fugitives
- Biological sources

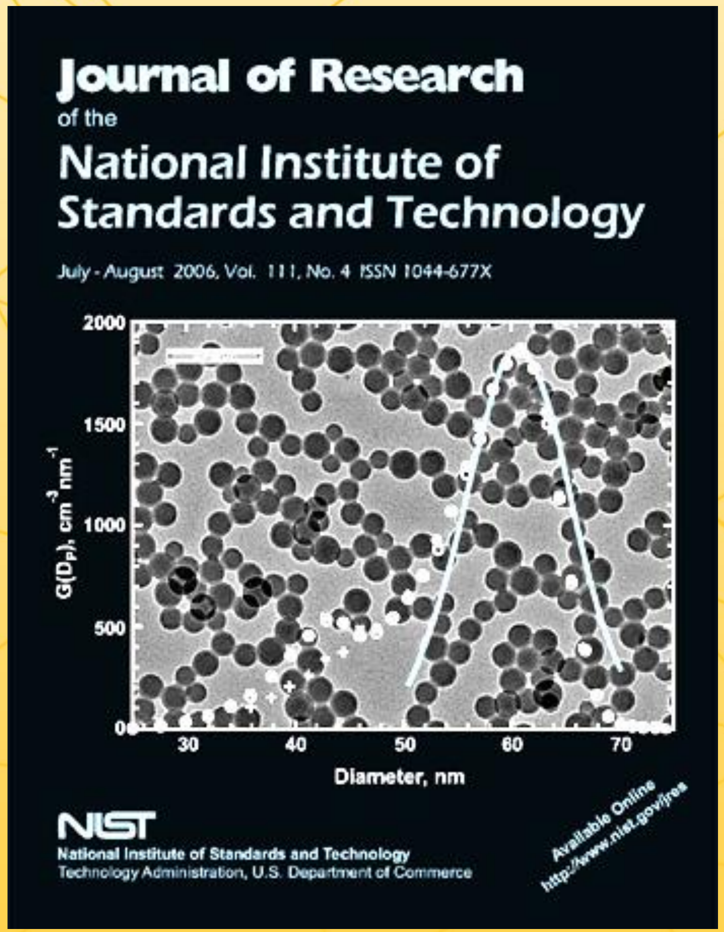
Exposure/Lifetime:

- Coarse fraction (2.5-10) lifetime of hours to days, distribution up to 100s km

# $PM_{2.5}$ Standard, U.S. EPA

- Established in 1997, $PM_{2.5}$ describes Particulate Matter (PM) that is 2.5 µm in diameter and smaller, $D_p < 2.5$ µm
- 24-hour standard: 65 µg/m$^3$, 3 yr avg, 98th percentile concentration; reduced to 35 µg/m$^3$ since 2006
- Annual standard: 12 µg/m$^3$ in 2012, 3-yr average of annual mean concentration

# ISO, NIST-SRM, and NFPA Standards




Mulholland, Pui et al., *J. Research NIST* 111:257-312 (2006)

**ISO/FDIS 15900**

Determination of <u>particle size distribution</u> – Differential electrical mobility analysis

**ISO/WD 27891**

Calibration of aerosol <u>particle number concentration</u> measuring instruments

**NFPA 96**

Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations – reduce air velocity through any duct to 500 ft/min from 1500 ft/min (Note: 42% Bldg, 28% Transport, 30% manufacturing)

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# Former Students/Post-docs

- Chuen-Jinn Tsai, **Chair Professor**, Taiwan Chiao Tung University, NSC Coordinator
- Xiang Zhang, UC Berkeley **Chancellor's Professor** and US NAE Member; **President** of University of Hong Kong
- Scott Earnest, **Deputy Director** of National Institute for Occupational Safety and Health (NIOSH)
- Seungki Chae, **Vice President, Samsung Semiconductors**; Senior VP, Samsung Display
- Yan Ye, Senior Director, Applied Materials
- **Da-Ren Chen**, **Chair Prof.**; **Shawn Chen**, Assistant Professor, Virginia Commonwealth University
- **Jing Wang**, Assoc. Prof., ETH Zurich
- **Changhyuk Kim**, Assistant Prof., Pusan National U.
- Visiting Scholar, X.Q. Wang, **Vice President of PetroChina**

# Particle Technology Laboratory (PTL) Family: Former Students/Post-docs/ /Visiting Scholars

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# UMN Center for Filtration Research (CFR)

Corning

The member companies of CFR have $28 billion annual sales (est.) in filtration industry. Applications include

- Removal of $PM_{2.5}$ pollutants
- Engine emission removal
- Cabin air filter for automobiles/airplanes
- Respirator and personal protection equip

# Objectives

- Foster industry/university collaboration in filtration through
  - graduate education
  - research
  - continuing education and technology transfer
- Help University to become more relevant in its research and education
- Encourage industry to utilize the knowledge and skill base available at the University to make itself more competitive in the global market place.

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# Technical Objectives

- Perform fundamental filtration research and theoretical modeling
- Develop improved experimental methods useful for filtration research, filter characterization, and filter testing
- Keep abreast of development in fundamental filtration science and new industry and government initiatives
- Seek new application of scientific knowledge to practical filtration problems

# Center for Filtration Research (CFR)
# $54^{th}$ Review Meeting, October 25-26, 2018
# Corning Incorporated Headquarter
# Corning Valley, Elmira, New York

Host:

Dr. Liming Wang

Director, Corning Research Center, China

# CFR Member Requests (2018)

- Air Intake Filter Loading by Mixture of Solid and Oil Particles
- Characterization of CMP Particles using Aerosolization Method
- Ultra-high Efficiency Filter Tests
- HVAC Filter Loading by Ammonium Sulfate and Ammonium Nitrate Submicron Particles and the Effect of Mixing with Combustion Soot
- Global Air Pollutant D/B and Real-life Filter Loading Test Rig Development
- Modeling of ISO Dust Dispersers and Measurement of Size Distribution of ISO Standard Dusts by Shadowgraphy Method
- Utilizing the WRF Modeling System to Simulate Atmospheric Flow over Beijing for SALSCS Evaluation
- Effect of Wash Coatings on Wall Flow Filter Performance and Filter Structure Analysis using 3D Image Scanner
- High Loading Capacity Nanofiber Filter Media
- Microbial Growth on Filter and Insulating Materials
- Particle Loading on Two-Stage Filtration System
- Surface Particle Removal using Dry/Wet Methods
- Electret Filter Loading: Effect of Fiber Structure and Charge Density
- Liquid Filtration Modeling: Effect of Chemical and Physical Factors

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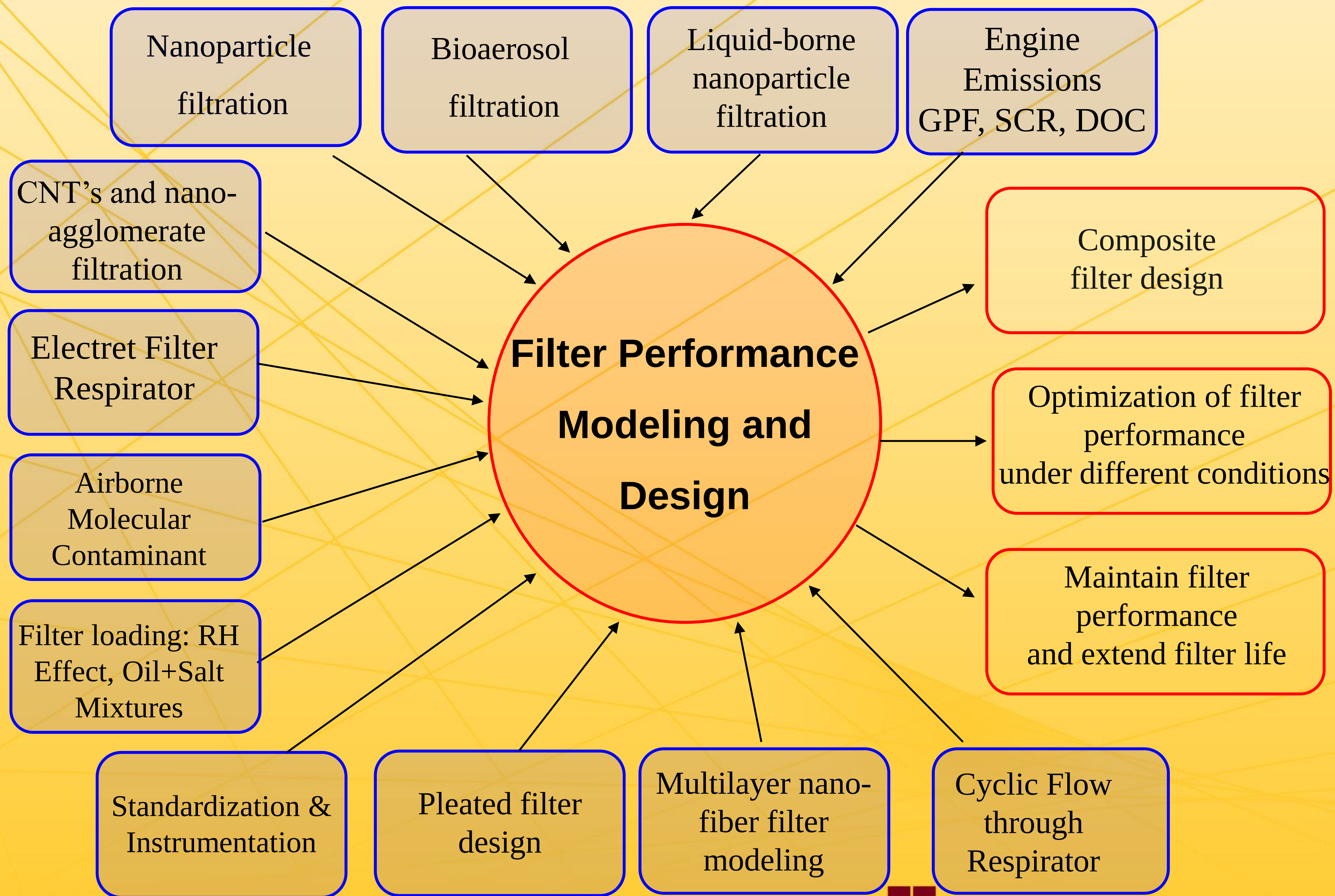
# Comprehensive Filter Modeling and Design

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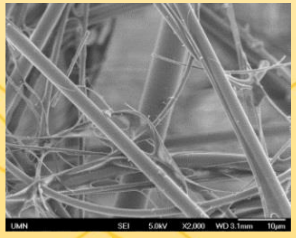
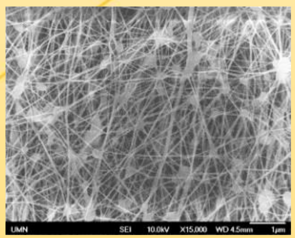
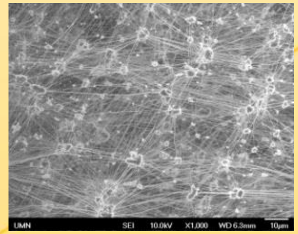
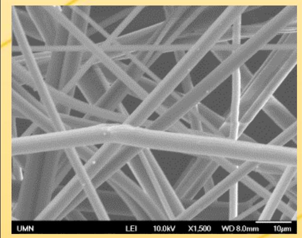
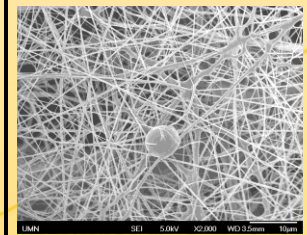
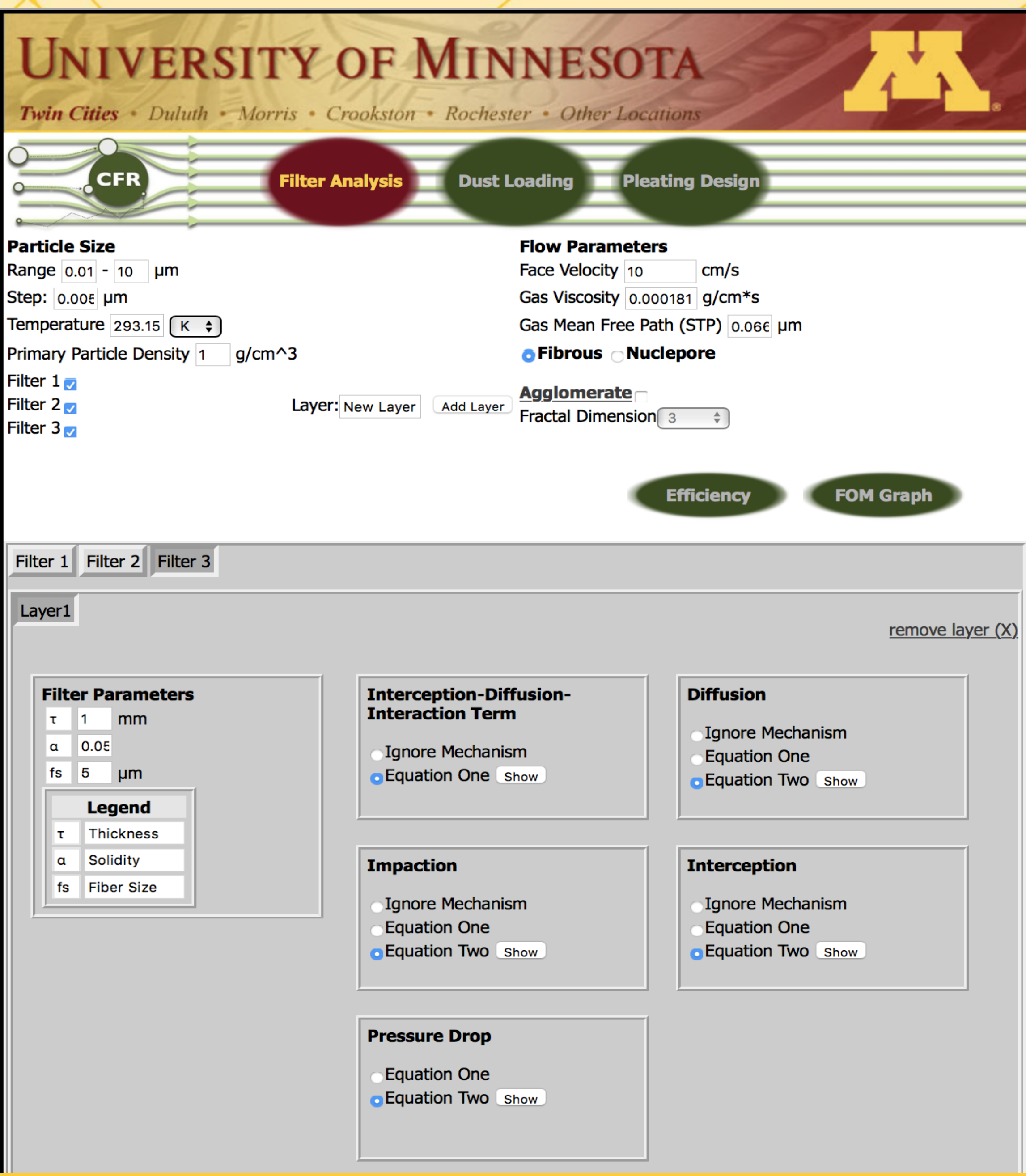
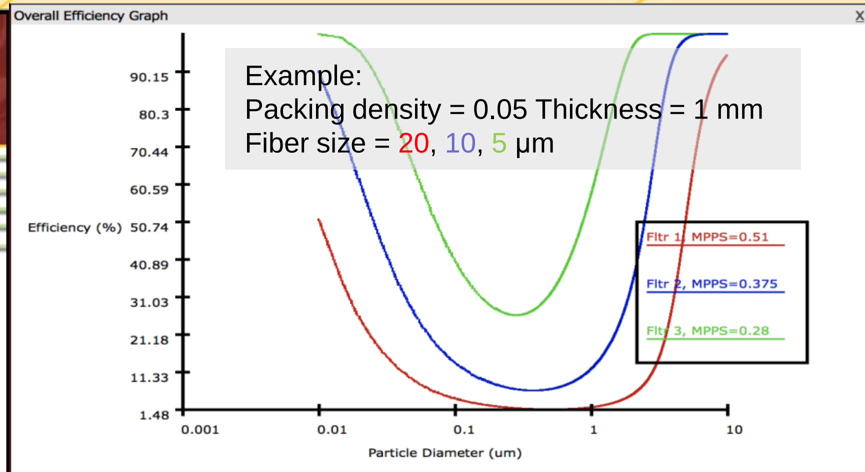
# Comparison of Different Types of Filter Media

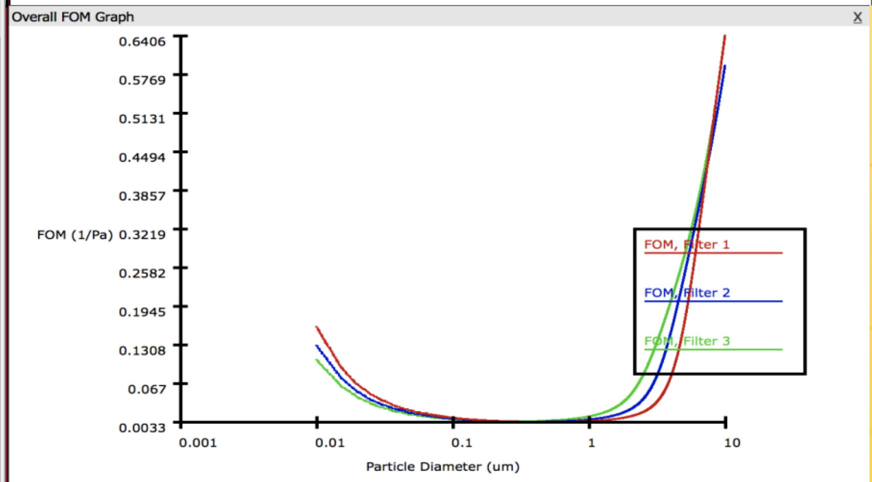
| Types | **Glass Fiber** | **PTFE** | **Ultrafine Nanofiber** | **Electret** | **Traditional nanofiber** |
|---|---|---|---|---|---|
| SEM Image |  |  |  |  |  |
| Fiber diameter (μm) | 0.4-0.5 | 0.02-0.12 | 0.02-0.15 | 10-20 | 0.15-0.3 |
| Thickness (μm) | 350-500 | 5-15 | 80-150 | 500-800 | 5-20 |
| Efficiency (%) for 0.3 um @ 5 cm/s | ≥ 99.97 | ≥ 99.97 | ≥ 99.97 | ≥ 95 | ≥ 80 |
| Pressure drop (Pa) | ~300 | ~150 | ~150 | ~10-15 | ~15-25 |
| Mechanism (cross-section) | Depth filtration | Surface filtration | Depth filtration | Depth filtration | Surface + Depth |

# Software Solution for Filter Analysis



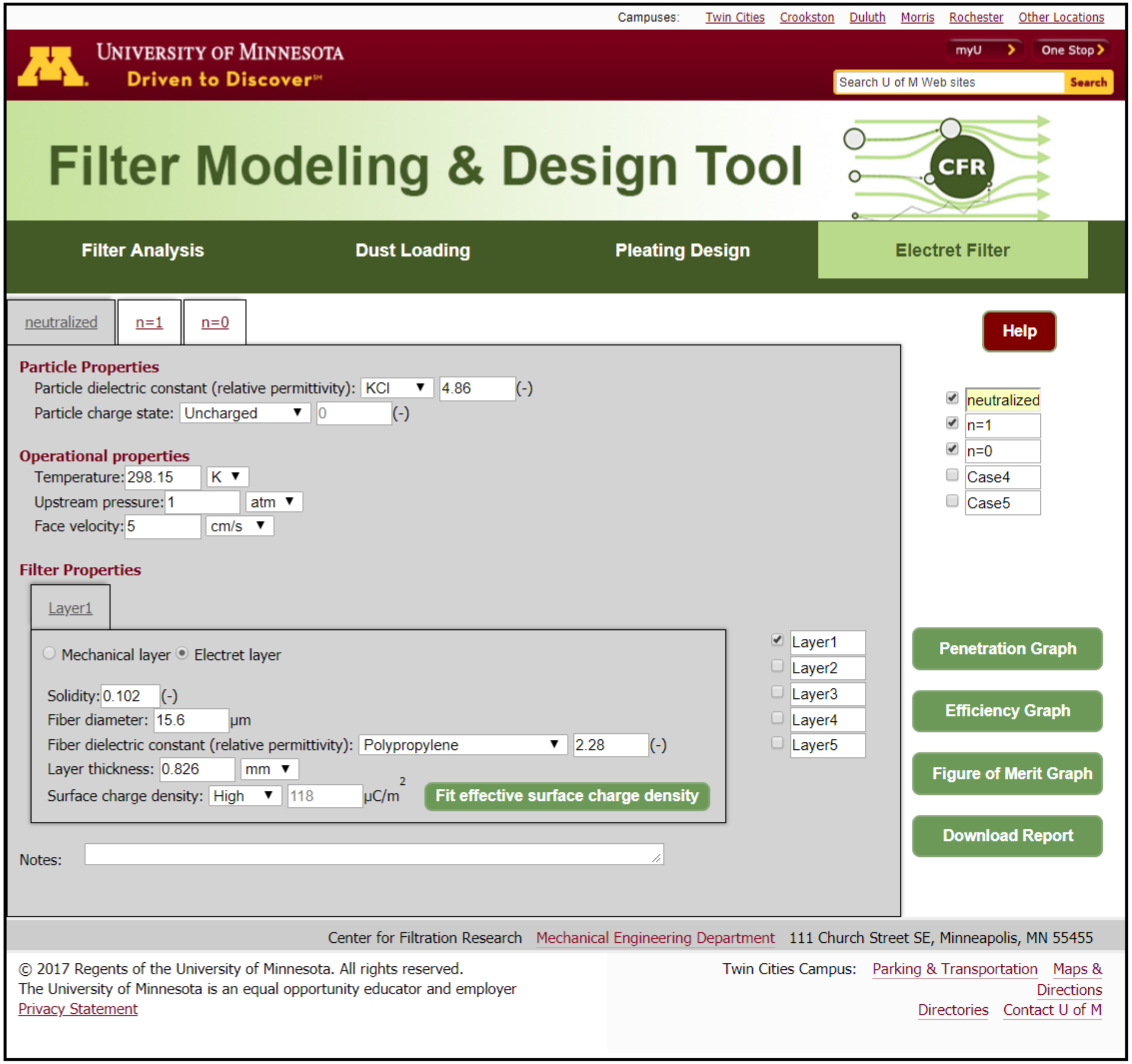

| | 0.01 | 0.015 | 0.02 | 0.025 | 0.03 | 0.035 | 0.04 | 0.045 | 0.05 |
|---|---|---|---|---|---|---|---|---|---|
| Fltr 3, MPPS=0.28 | 99.9433 | 98.8531 | 95.5884 | 90.6878 | 85.1248 | 79.5541 | 74.3038 | 69.5041 | 65.1828 |
| Fltr 2, MPPS=0.375 | 90.1227 | 74.7376 | 61.5572 | 51.4982 | 43.9015 | 38.0813 | 33.5339 | 29.9111 | 26.9734 |
| Fltr 1, MPPS=0.51 | 51.3796 | 34.7512 | 25.594 | 19.99 | 16.2729 | 13.6557 | 11.7279 | 10.2569 | 9.1026 |



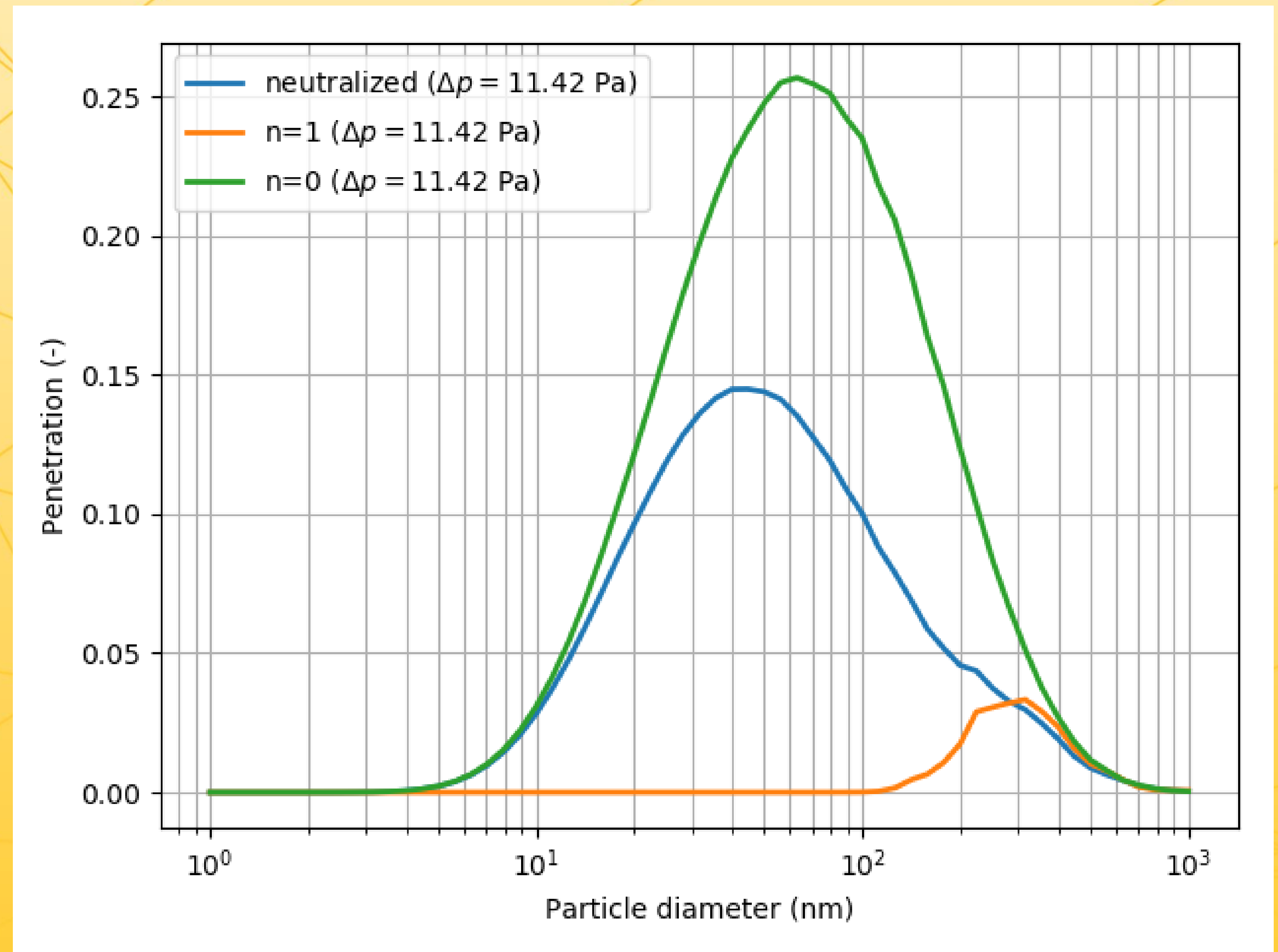

| | 0.01 | 0.015 | 0.02 | 0.025 | 0.03 | 0.035 | 0.04 | 0.045 |
|---|---|---|---|---|---|---|---|---|
| FOM, Filter 3 | 0.1058063 | 0.063245 | 0.0441758 | 0.033601 | 0.0269714 | 0.022469 | 0.0192338 | 0.016809 |
| FOM, Filter 2 | 0.1293088 | 0.0768532 | 0.0534007 | 0.0404175 | 0.0322896 | 0.0267757 | 0.022817 | 0.019852 |
| FOM, Filter 1 | 0.1599847 | 0.0947234 | 0.0655874 | 0.0494777 | 0.0394029 | 0.0325743 | 0.0276753 | 0.024008 |

Figure of merit for composite filters: Wang, Kim and Pui, *Aerosol Science & Technology*, 42, 722 – 728 (2008).

# Interface of web-based electret filter performance model and design tool



# Results of web-based electret filter performance model and design tool

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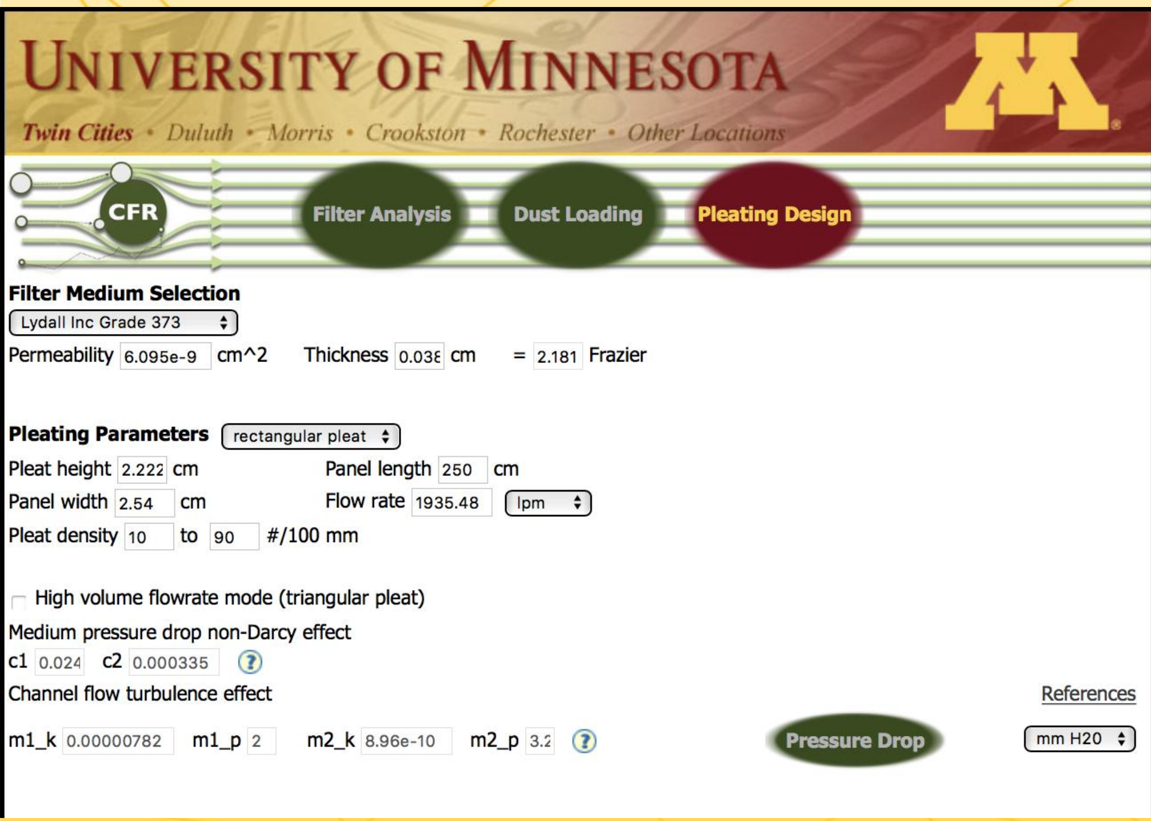
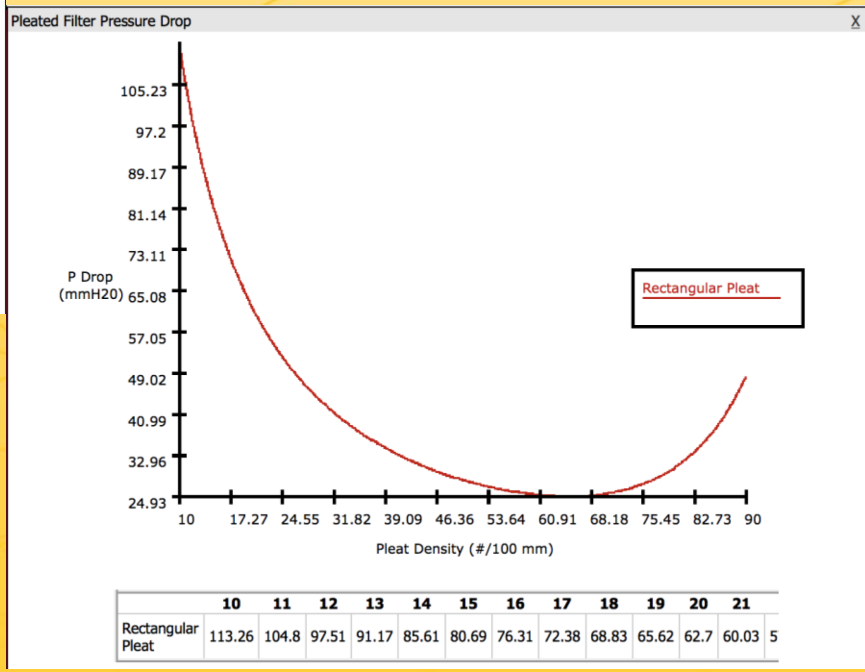
# Software Solution for Pleating Design




Chen, Liu and Pui, *Aerosol Sci. Technol*. 23:579-590 (1995).

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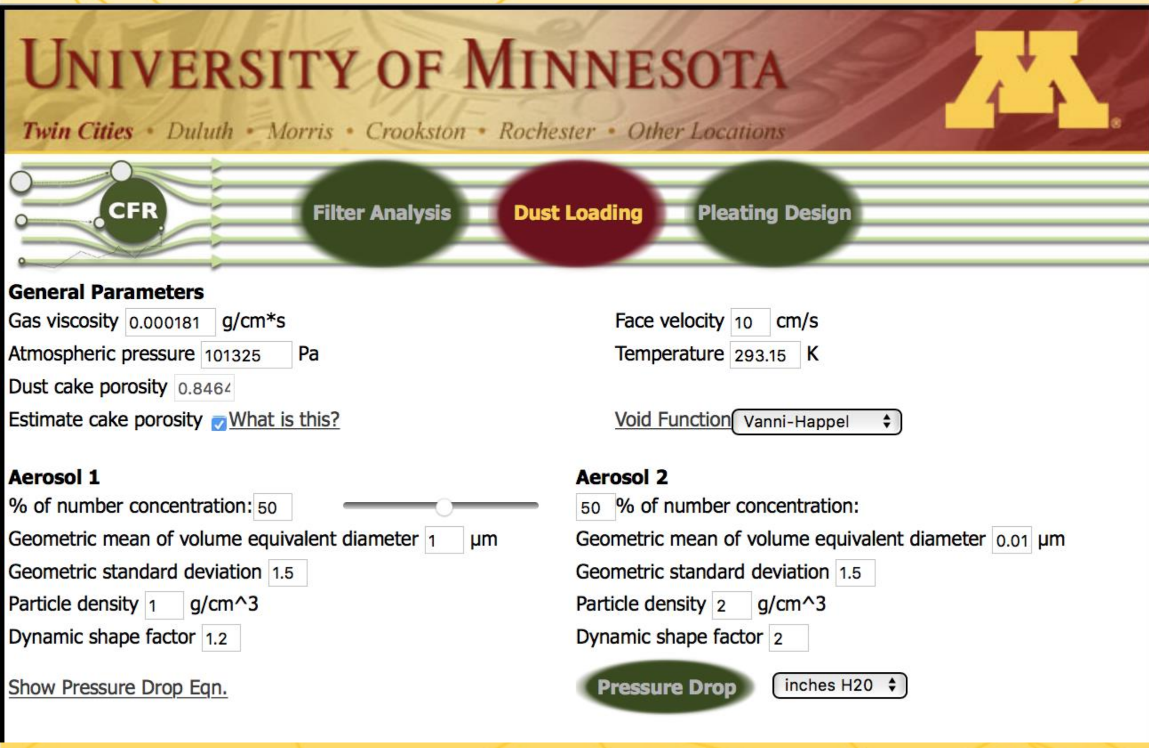
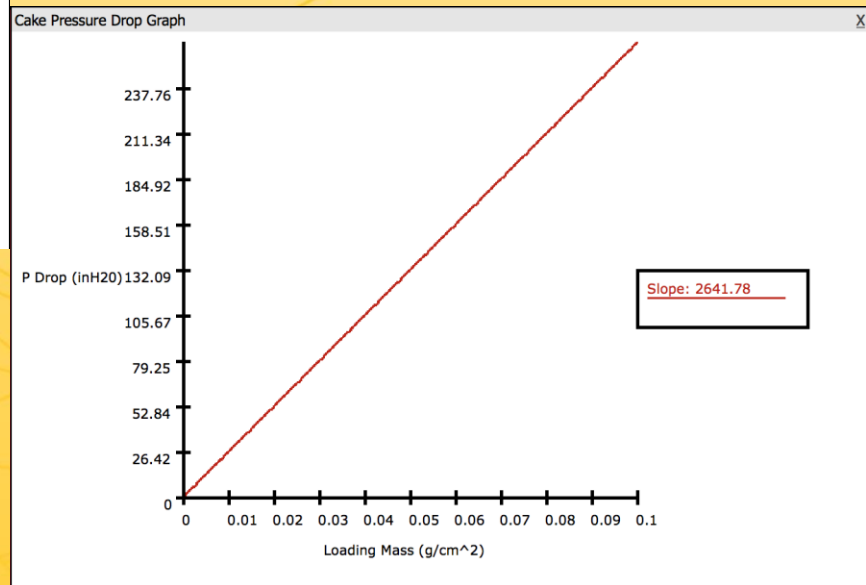
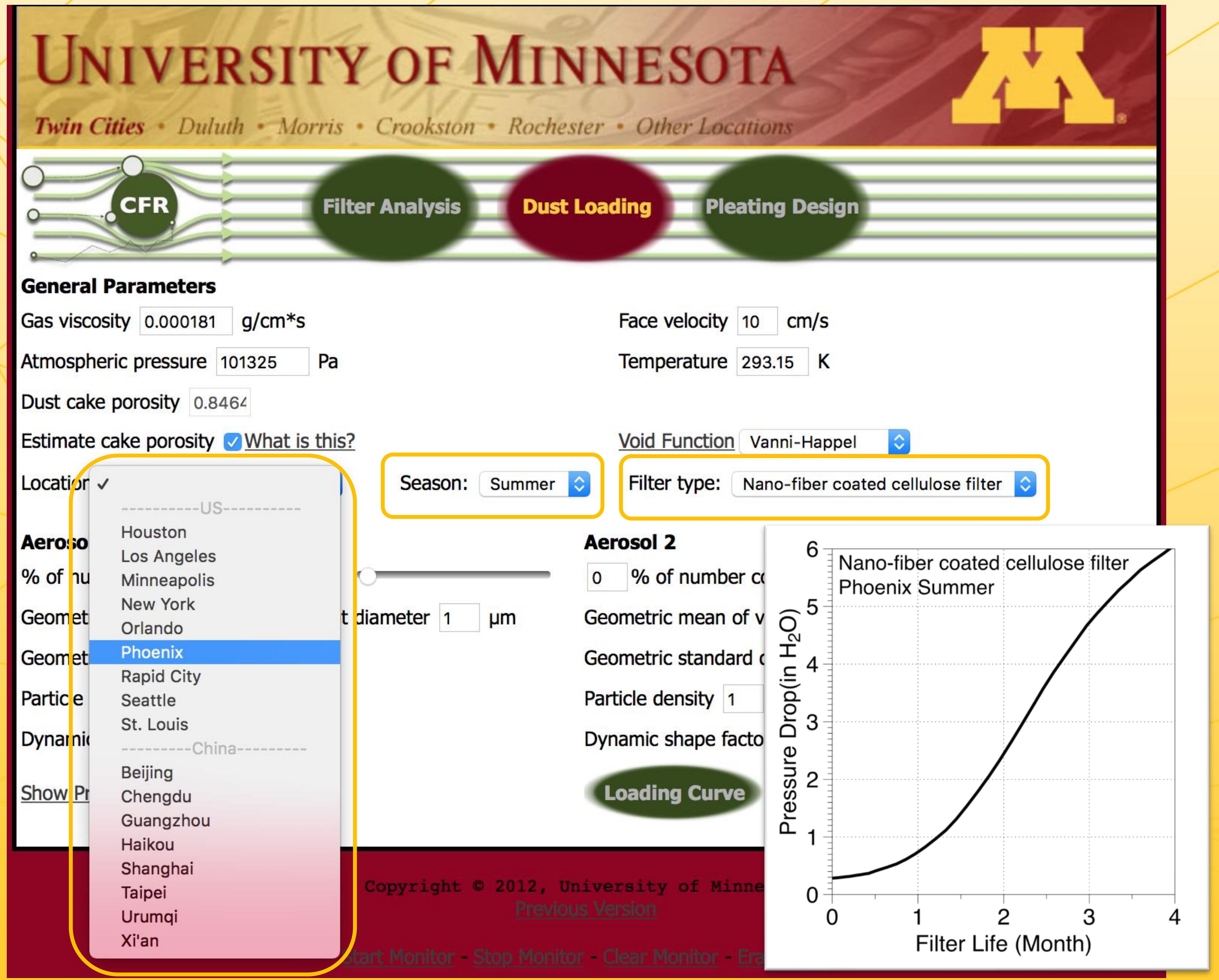
# Software Solution for Dust Loading




| | 0 | 0.001 | 0.002 | 0.003 | 0.004 | 0.005 | 0.006 | 0.007 | 0.008 | 0.009 | 0.01 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Slope: 2641.78 | 0 | 2.6418 | 5.2836 | 7.9253 | 10.5671 | 13.2089 | 15.8507 | 18.4925 | 21.1343 | 23.776 | 26.417 |



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Twin Cities • Duluth • Morris • Crookston • Rochester • Other Locations
CFR
Filter Analysis
Dust Loading
Pleating Design
General Parameters
Gas viscosity 0.000181 g/cm*s
Face velocity 10 cm/s
Atmospheric pressure 101325 Pa
Temperature 293.15 K
Dust cake porosity 0.8464
Estimate cake porosity What is this?
Void Function Vanni-Happel
Season: Summer
Filter type: Nano-fiber coated cellulose filter
----------US----------
Houston
Los Angeles
Minneapolis
New York
Orlando
Phoenix
Rapid City
Seattle
St. Louis
---------China---------
Beijing
Chengdu
Guangzhou
Haikou
Shanghai
Taipei
Urumqi
Xi'an
Aerosol 2
% of number c
Geometric mean of v
Geometric standard d
Particle density 1
Dynamic shape facto
Loading Curve
diameter 1 μm
Copyright © 2012, University of Minne
Previous Version
Start Monitor - Stop Monitor - Clear Monitor - Era
Nano-fiber coated cellulose filter
Phoenix Summer
Pressure Drop(in $H_2O$)
Filter Life (Month)
0
1
2
3
4
5
6

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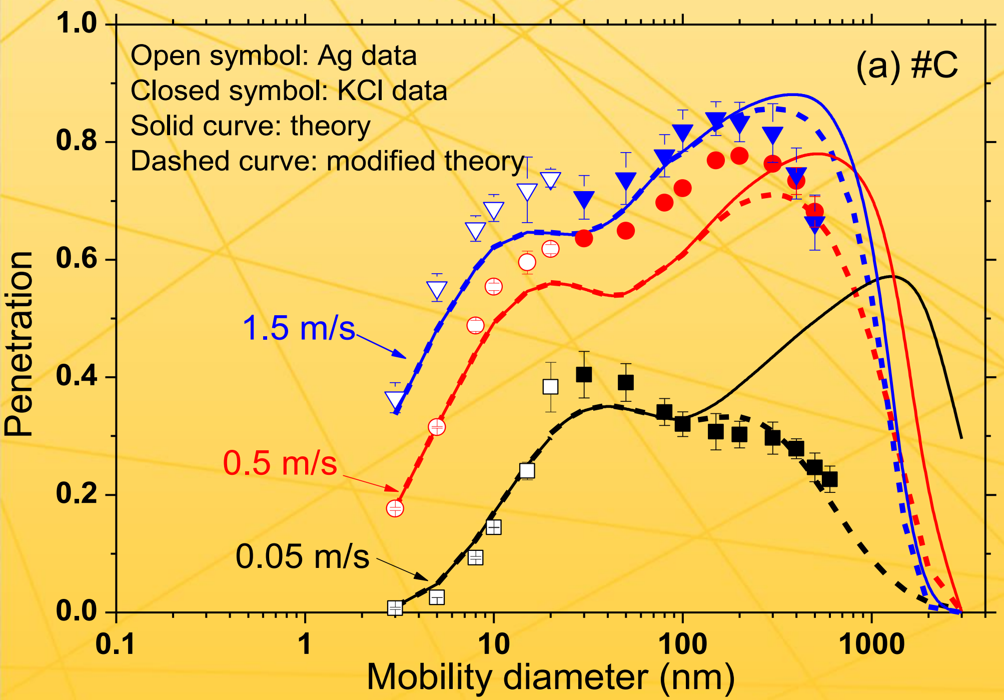
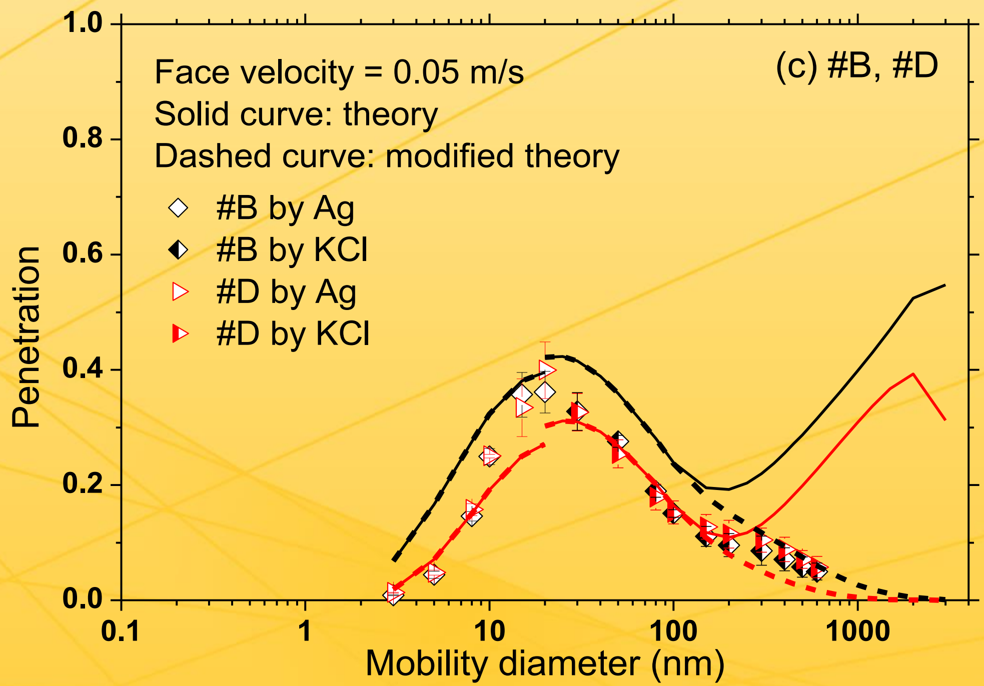
# Electret Filter Model for Predicting the Particle Penetrations

- The modified model (dashed curve) are in very good agreements with data.



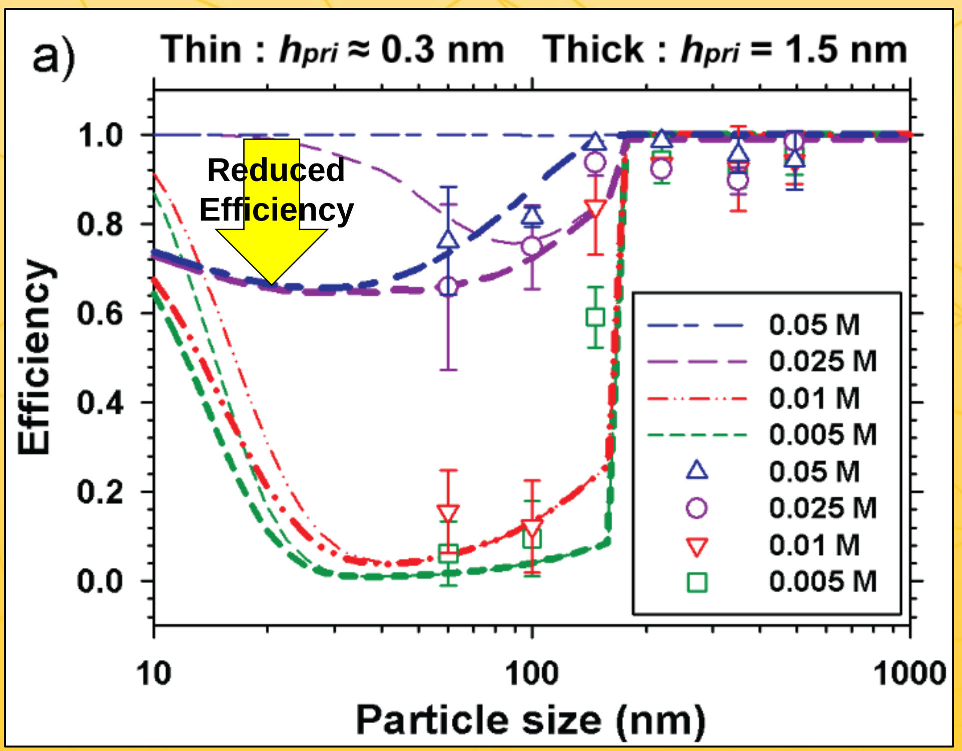


Chang, Chen, Pui, et al. AAQR 16(12):3349-3357 (2016)
Thompson et al., manuscript in preparation (2017)

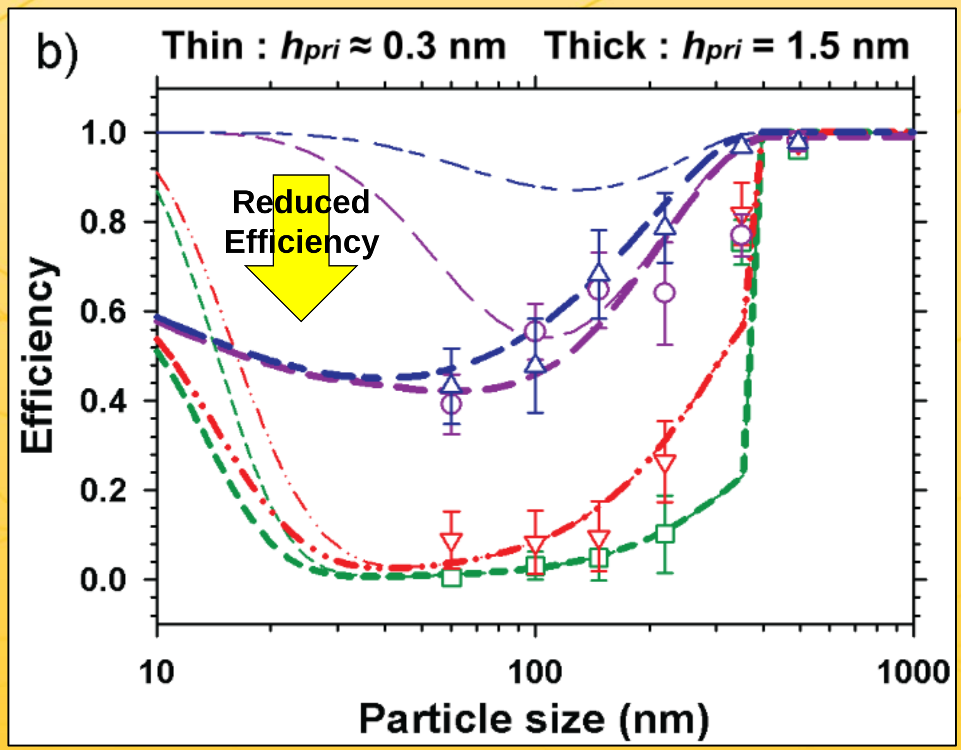
# Efficiency Considering Short-Range Repulsion

- Short-range repulsion at 1.5 nm
  - ✓ When considering the short-range repulsion, hydrodynamic drag resulted in detachment of particles on the pore walls.
  - ✓ Experiments and models agree better for different ionic strengths when considering the short-range repulsion.

**0.2-μm rated Nuclepore filter**

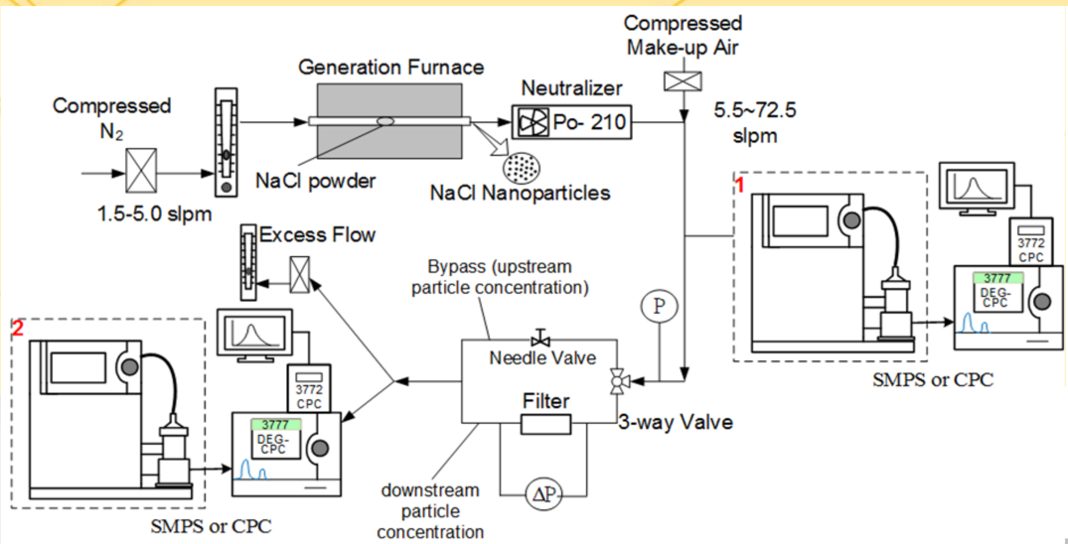



**0.4-μm rated Nuclepore filter**

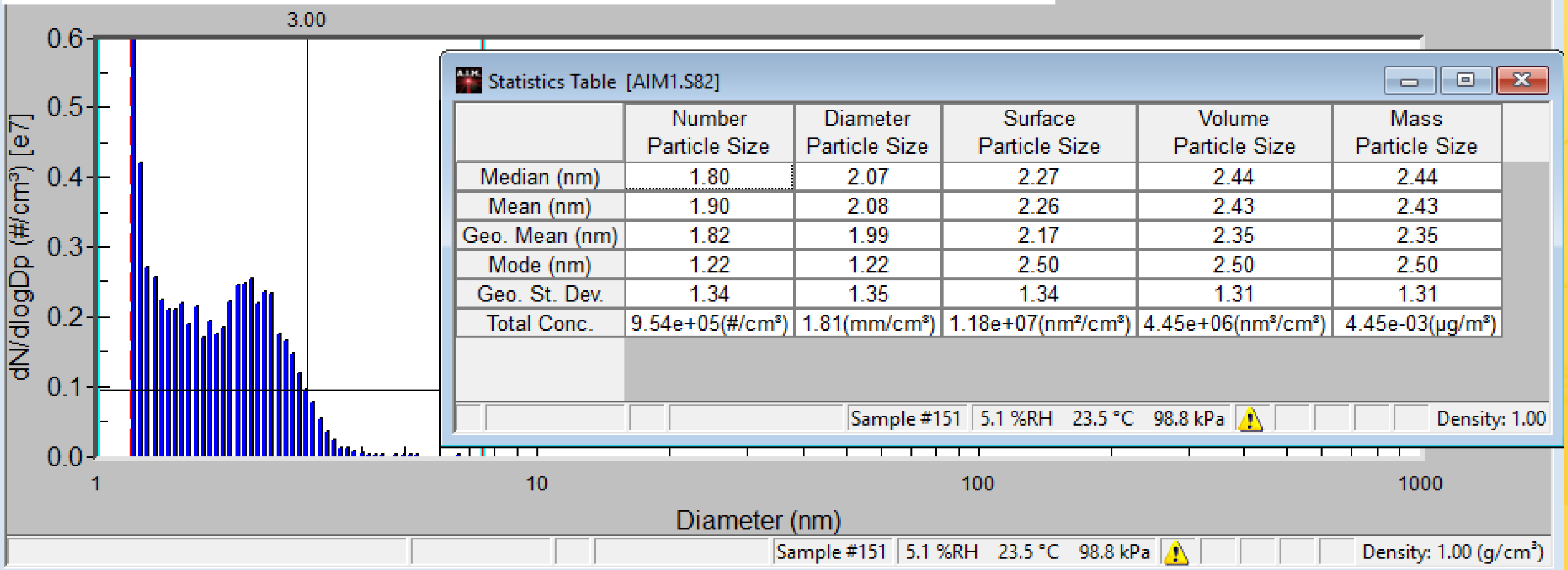



Lee, Segets, Pui, et al., *J. Membrane Sci.* 524:682-690 (2017)

# Sub-3 nm (1.5 nm) Nanoparticle Generation




1 nm Scanning mobility particle sizer spectrometer 3938E77




| | Number Particle Size | Diameter Particle Size | Surface Particle Size | Volume Particle Size | Mass Particle Size |
|---|---|---|---|---|---|
| Median (nm) | 1.80 | 2.07 | 2.27 | 2.44 | 2.44 |
| Mean (nm) | 1.90 | 2.08 | 2.26 | 2.43 | 2.43 |
| Geo. Mean (nm) | 1.82 | 1.99 | 2.17 | 2.35 | 2.35 |
| Mode (nm) | 1.22 | 1.22 | 2.50 | 2.50 | 2.50 |
| Geo. St. Dev. | 1.34 | 1.35 | 1.34 | 1.31 | 1.31 |
| Total Conc. | 9.54e+05(#/cm³) | 1.81(mm/cm³) | 1.18e+07(nm²/cm³) | 4.45e+06(nm³/cm³) | 4.45e-03(µg/m³) |

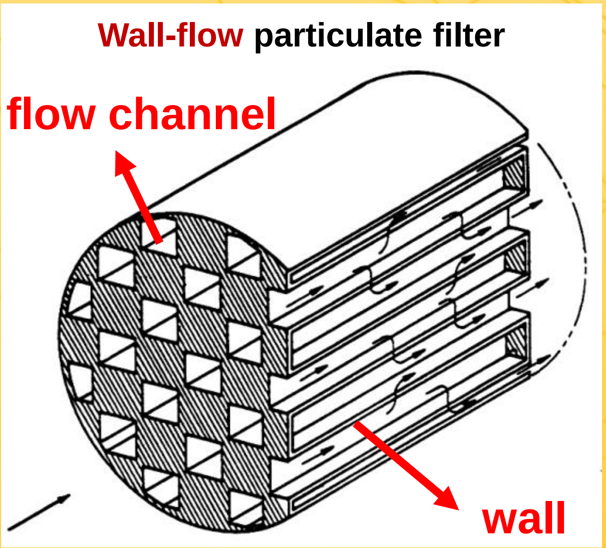
# Evaluation of High Efficiency Filters for 2 nm Particles

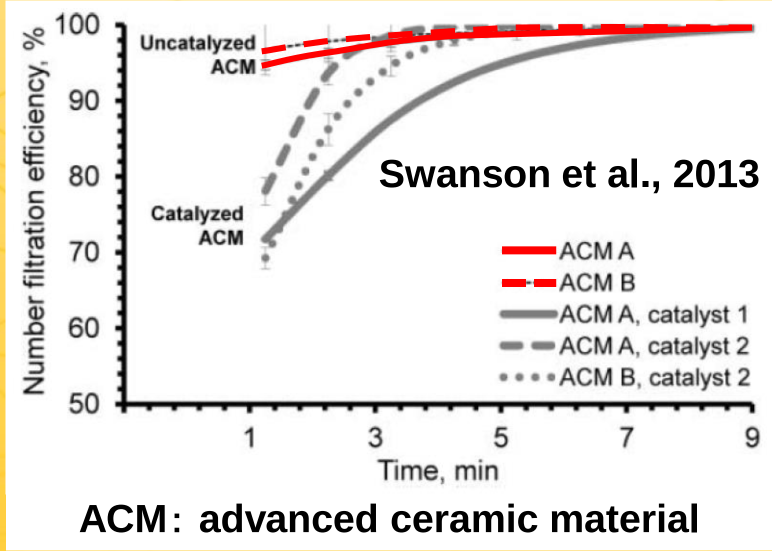
## Efficiency > 99.9999999%, Log Reduction Value (LRV)> 9

| FILTER MODEL | flow rate (slpm) | Sample time (min) | sampling flow volume (c.c.) by CPC | upstream conc. (#/c.c.) | downstream conc. (#/c.c.) | downstream counts | background conc. (#/c.c.) | background counts | Pen. | Lrv |
|---|---|---|---|---|---|---|---|---|---|---|
| **#1** | 8 | ~120 | 6000 | 6.50E+05 | 2.22E-03 | 13 | 2.05E-03 | 12 | 2.62 E-10 | 9.58 |
| **#2** | 10 | ~120 | 6000 | 4.36E+05 | 1.70E-03 | 10 | 1.85E-03 | 11 | 3.82 E-10 | >9.42 |
| **#3** | 20 | ~120 | 6000 | 3.15E+05 | 2.17E-03 | 13 | 2.68E-03 | 16 | 5.29 E-10 | >9.28 |
| **#4** | 30 | ~100 | 5000 | 3.00E+05 | 1.81E-03 | 9 | 2.07E-03 | 10 | 5.56 E-10 | >9.26 |
| **#5** | 50 | ~120 | 6000 | 2.50E+05 | 1.34E-03 | 8 | 1.14E-03 | 7 | 8.00 E-10 | 9.10 |
| **#6** | 60 | ~120 | 6000 | 2.45E+05 | 3.03E-03 | 18 | 3.84E-03 | 23 | 6.80 E-10 | >9.17 |
| **#7** | 75 | ~100 | 5000 | 1.00E+05 | 2.16E-03 | 11 | 2.07E-03 | 10 | 9.00 E-10 | 9.05 |

# Effect of Catalyst Coating on Filtration Performance of Diesel Particulate Filters

- Diesel particulate filters are widely used on diesel engines after-treatment system to mitigate the particulate matter emission.
- Usually, catalyst is applied onto the monolithic wall-flow particulate filter substrate, when both gaseous and particulate emissions need to be controlled. However, previous study (Swanson et al., 2013) showed that the soot removal efficiency decreases with catalyst coatings. We would like to investigate this phenomenum.

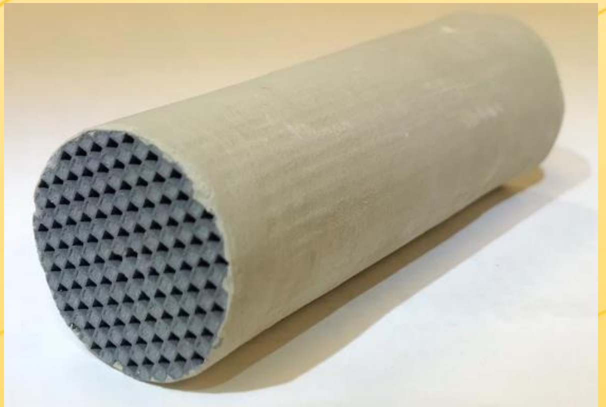


# Blank and Coated Samples

- Substrate: SiC; Outer diameter: 1”; Length: 3”;
- Cell density: 300 cpsi; Wall thickness: 12 mil.

| Sample # | | Catalyst Coating Amount |
|---|---|---|
| Blank | Blank-1 | 0.0% |
| | Blank-2 | 0.0% |
| | Blank-3 | 0.0% |
| | Blank-4 | 0.0% |
| A | A-1 | 24.3% |
| | A-2 | 23.5% |
| B | B-1 | 49.3% |
| | B-2 | 48.9% |
| C | C-1 | 97.2% |
| | C-2 | 100.0% |



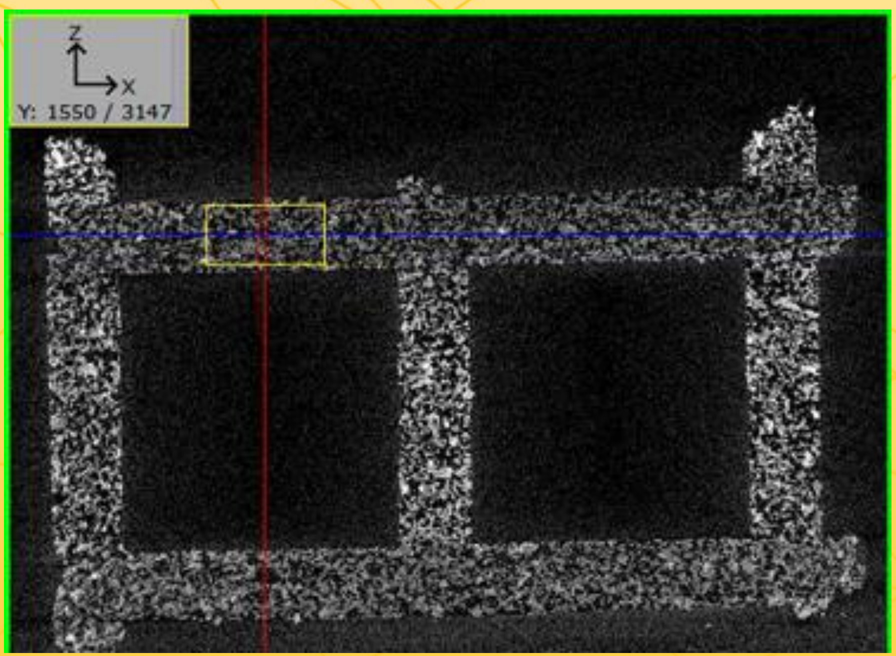
* 100% coating amount: the coating amount needed for desired catalytic conversion.

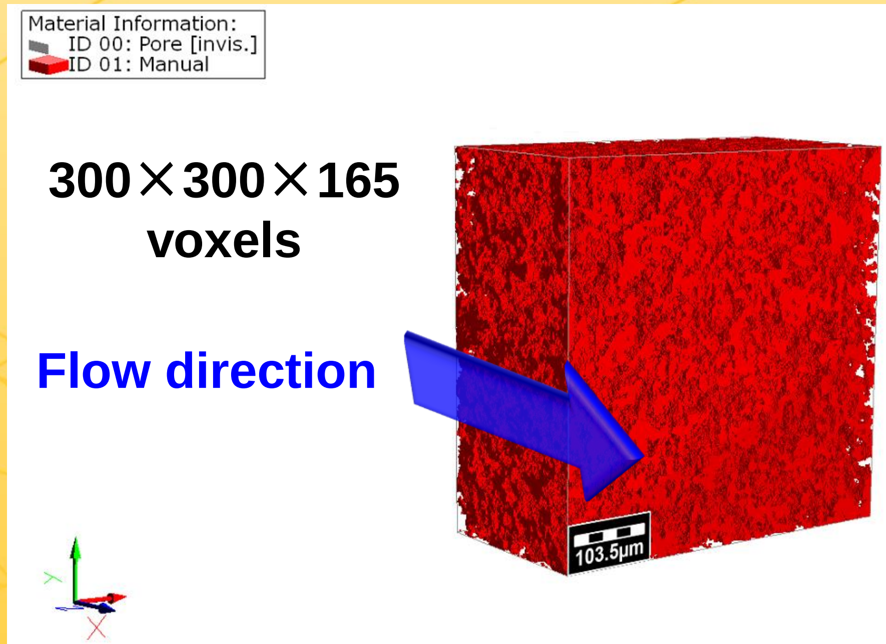
* cpsi: cells per square inch.

* mil: 1/1000 inch.

# Simulation Method

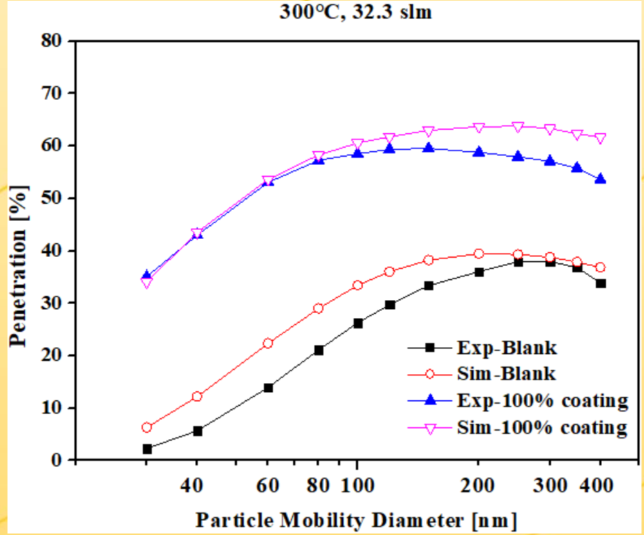
- Micro X-ray computed tomography (CT) can provide a 3D reconstruction of the micro-porous structure.
- Importing the micro-CT scan images of the blank sample to GeoDict.

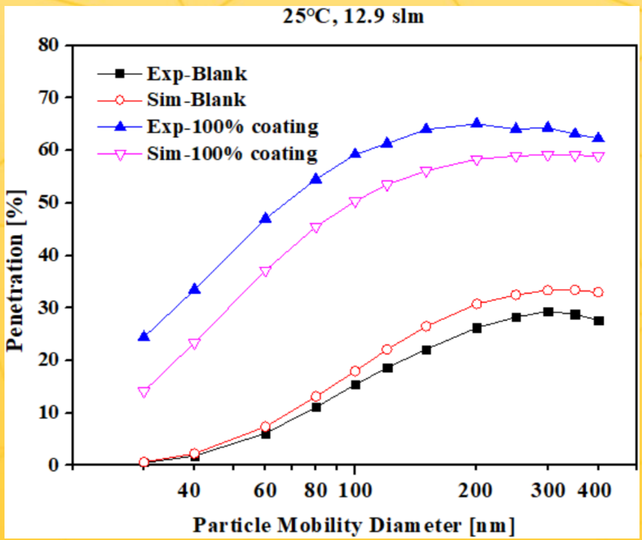


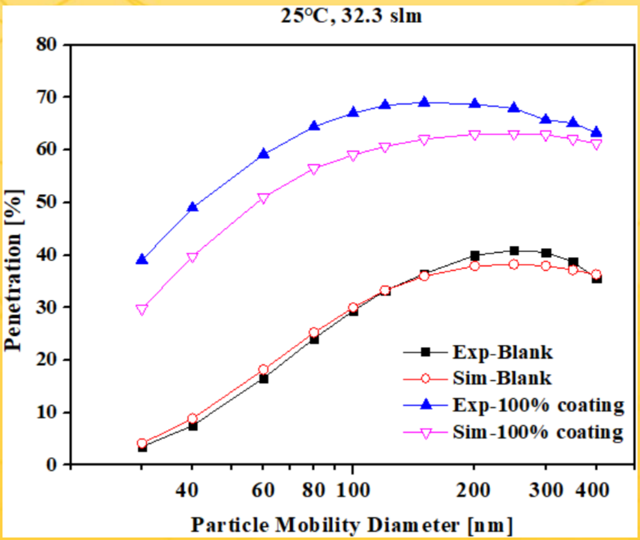



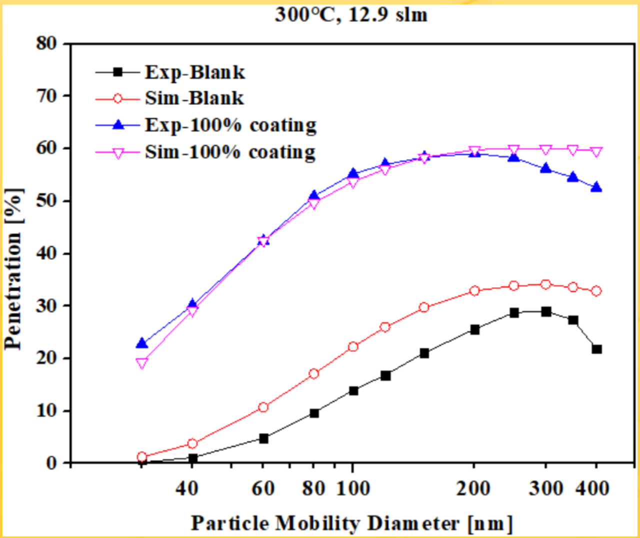
# Initial efficiency – blank and coated samples

- At all test conditions, penetration of blank samples is lower than that of samples with 100% coating amount – higher efficiency for blank samples. The experimental results agree well with simulation.

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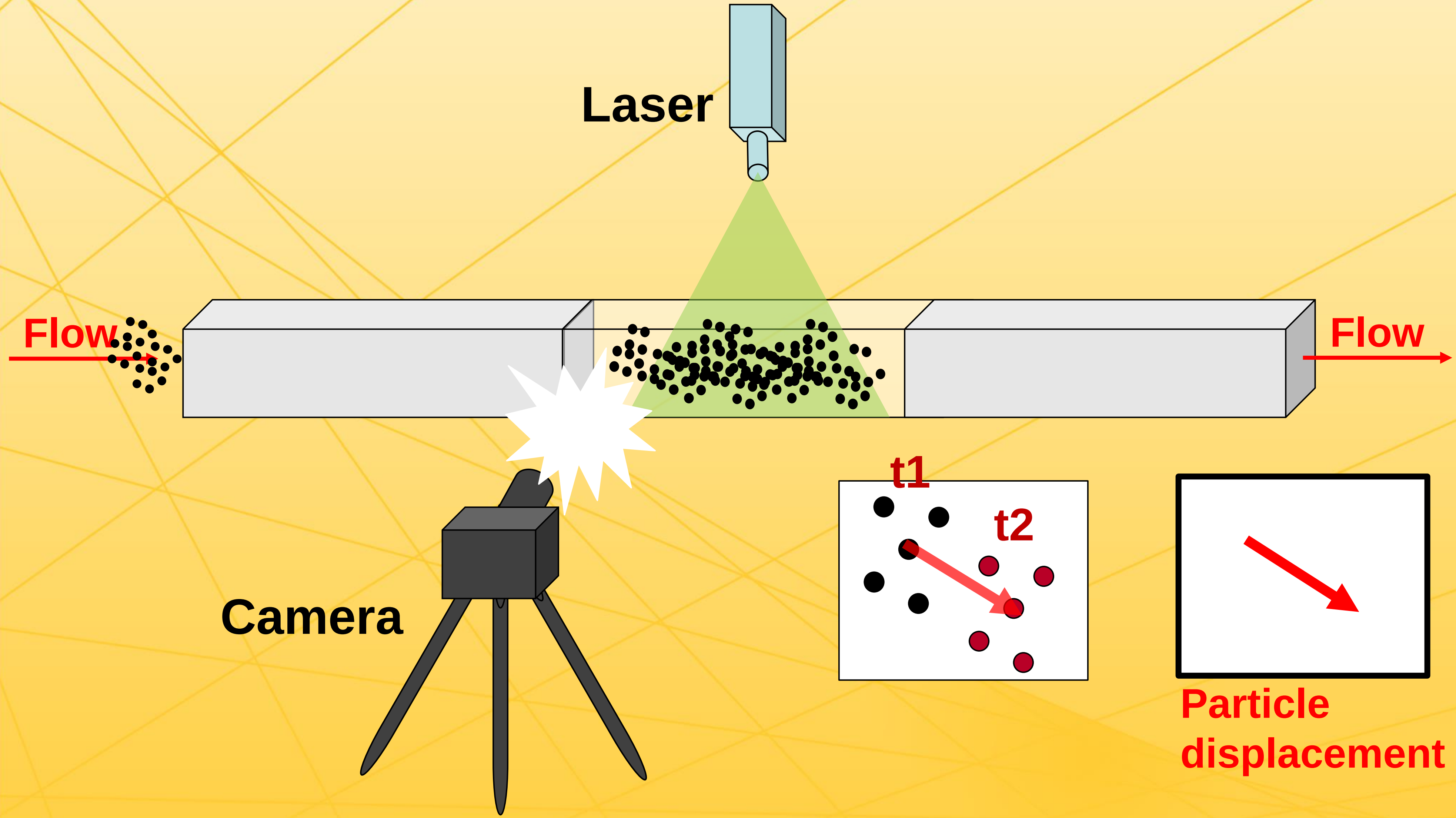
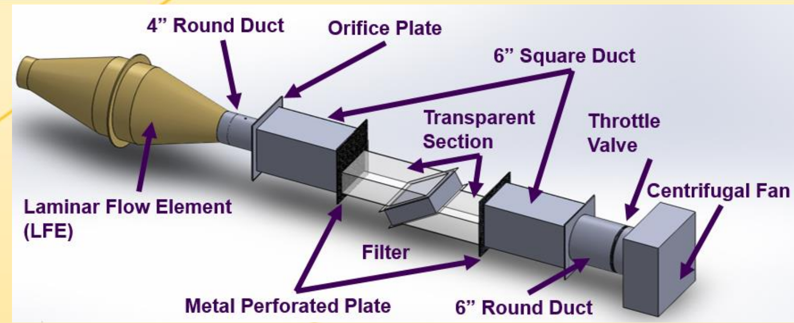
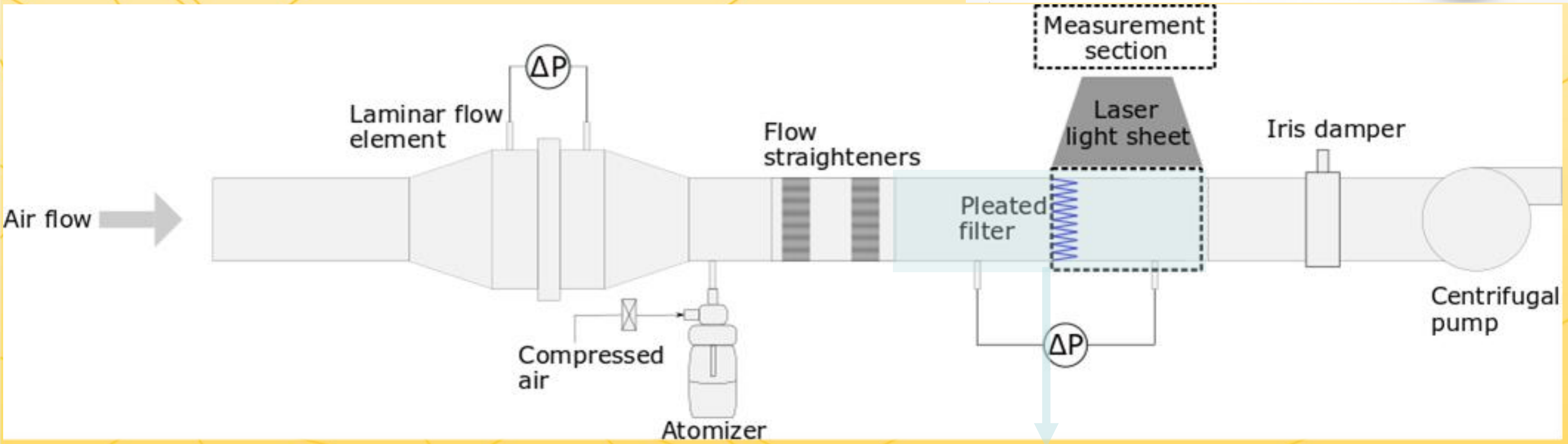
# Particle Image Velocimetry (PIV)



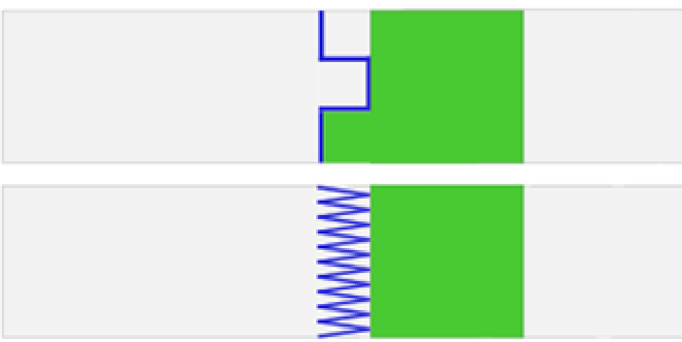

An optical imaging technique to measure fluid velocity vectors at many points simultaneously

# Pleated Filter Evaluation

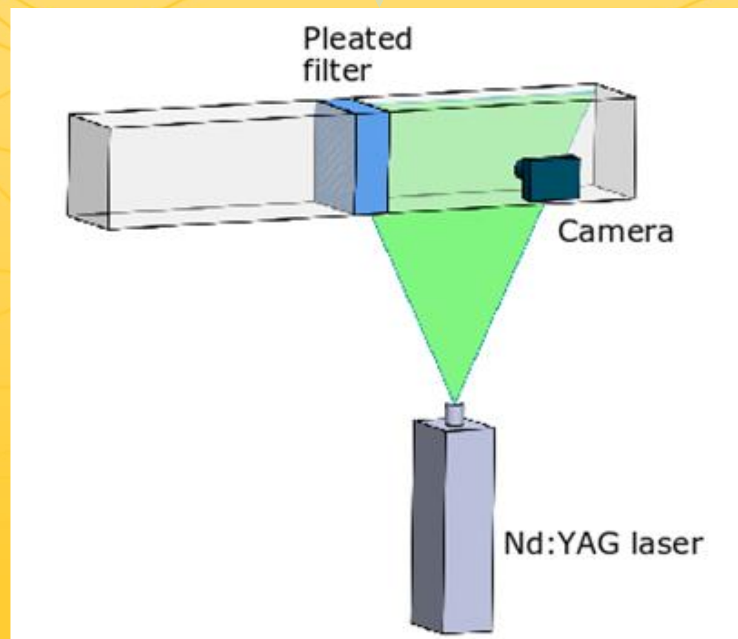


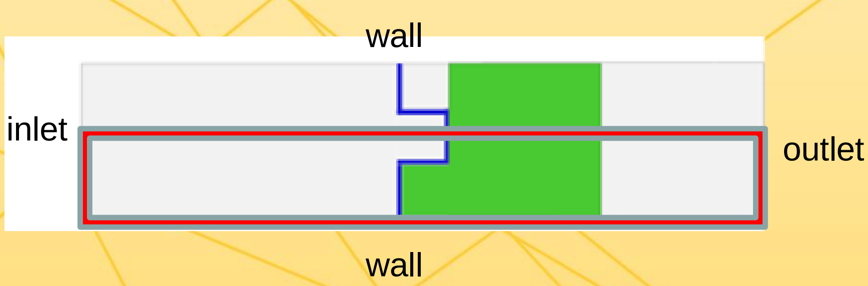

(a) Rectangular pleated filter

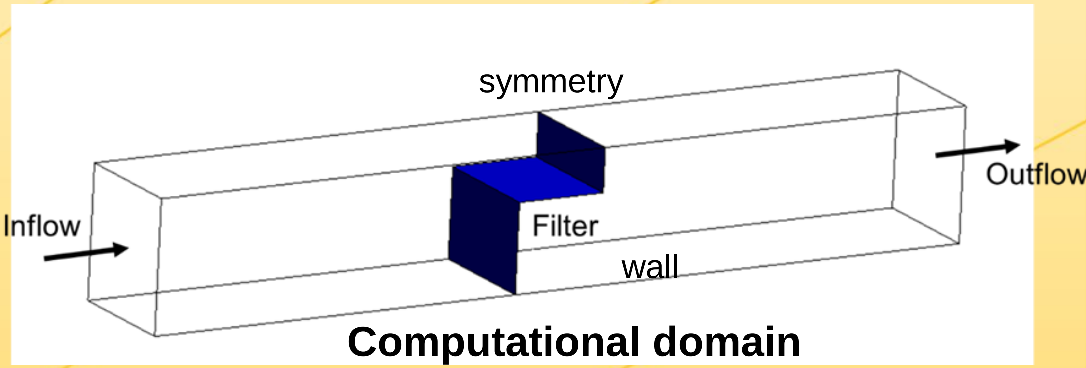


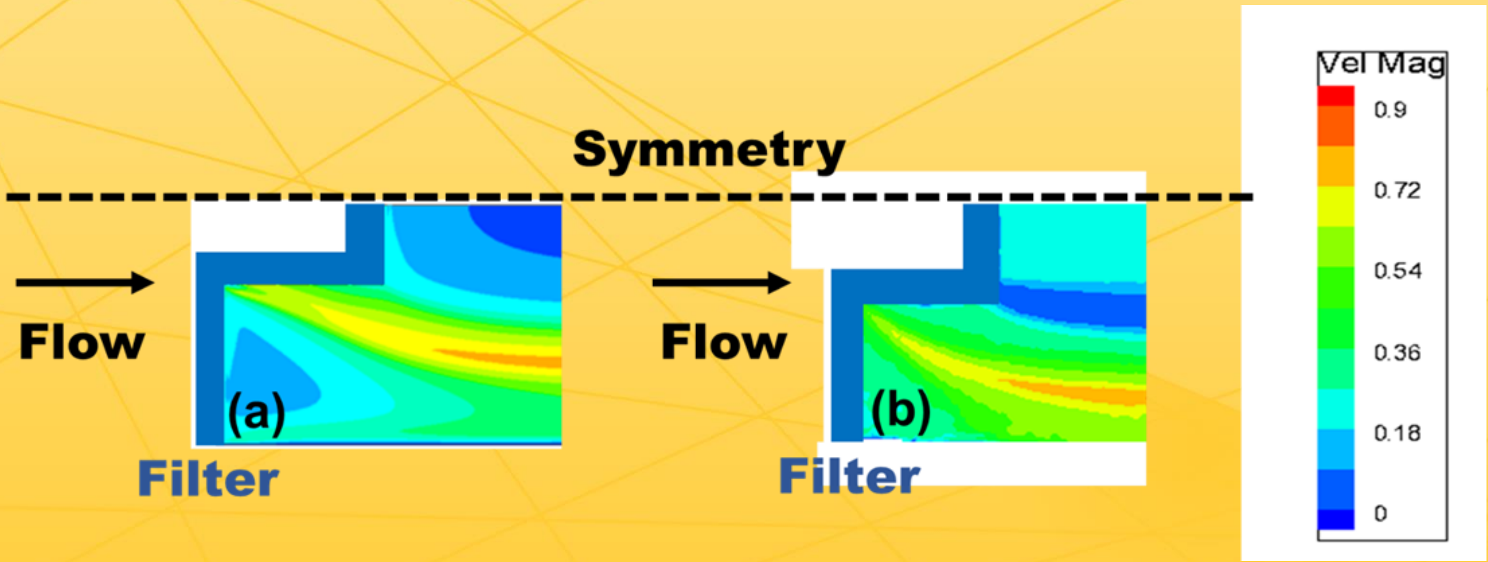
(b) commercial pleated filter



# PIV vs CFD




(a) CFD

(b) PIV

**Time-averaged contour plots at 0.32 m/s**

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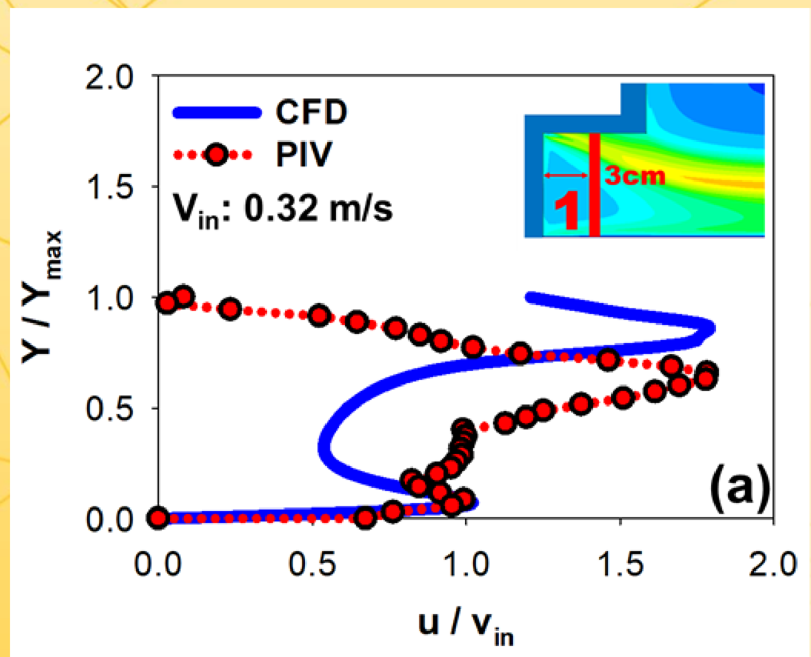
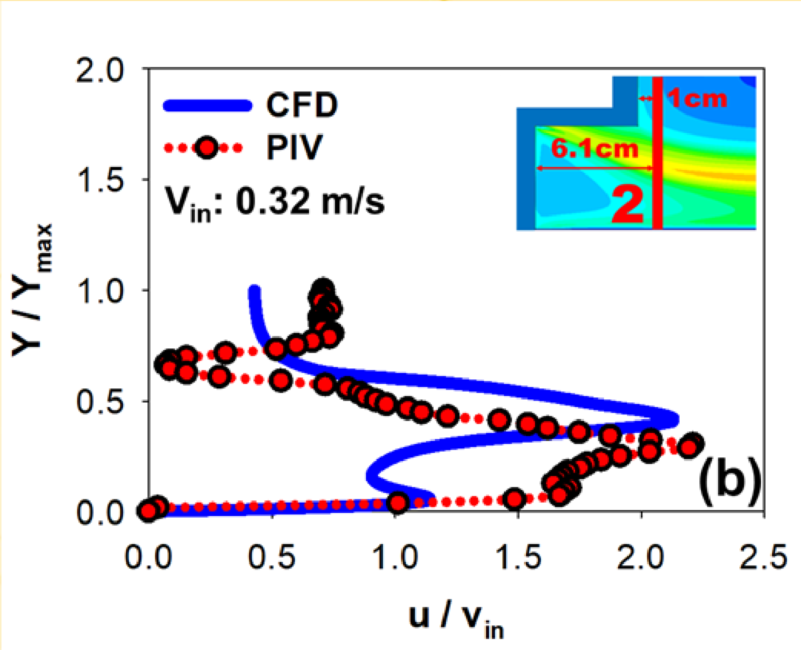
# PIV vs CFD: Velocity Profiles




(a) at x = 3 cm

(b) at x = 6.1 cm

**Normalized streamwise velocity distribution along the y-axis**

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  - SALSCS (2nd Gen) for $CO_2$ Reduction
  - SALSCS (3rd Gen) for Green Community

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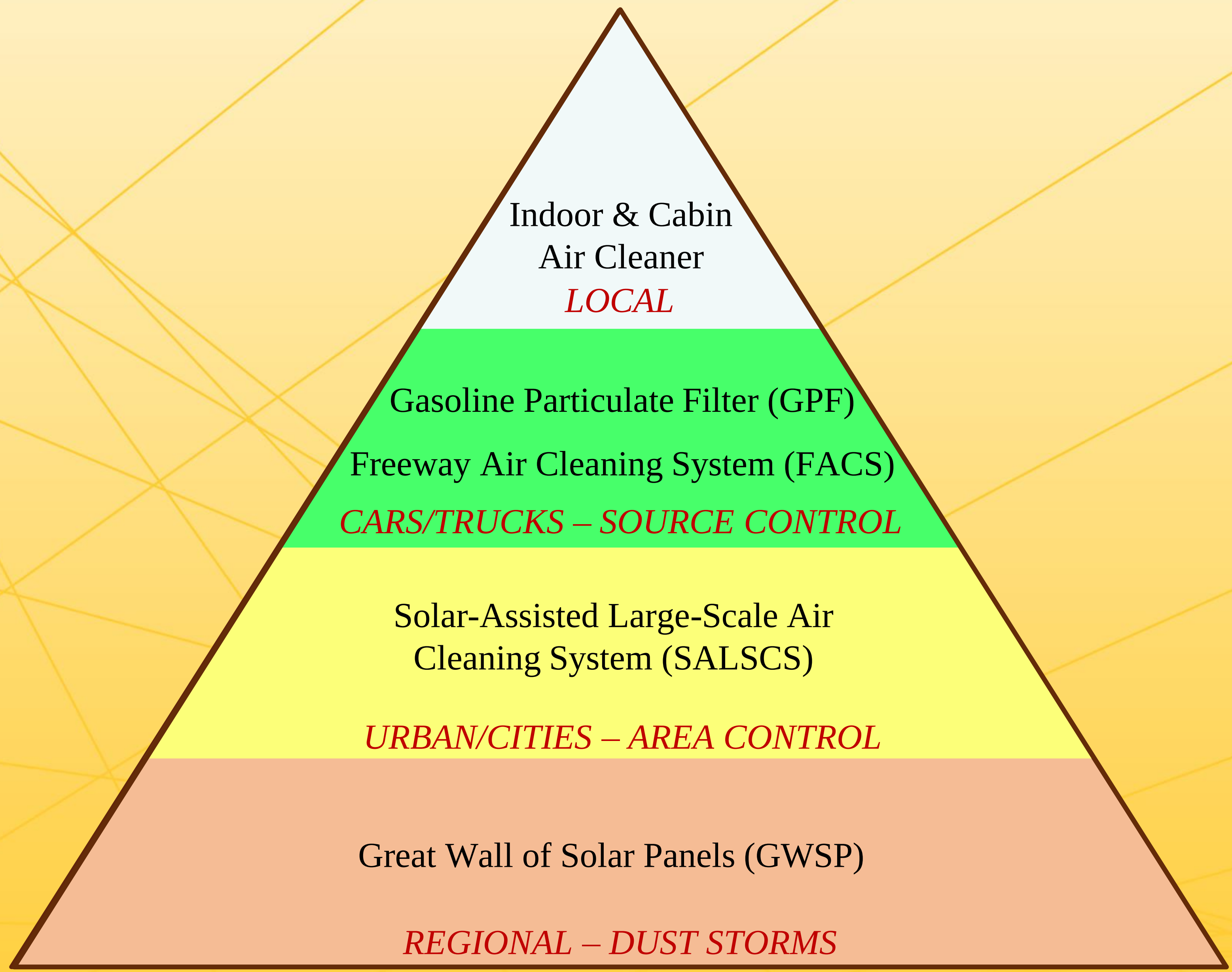


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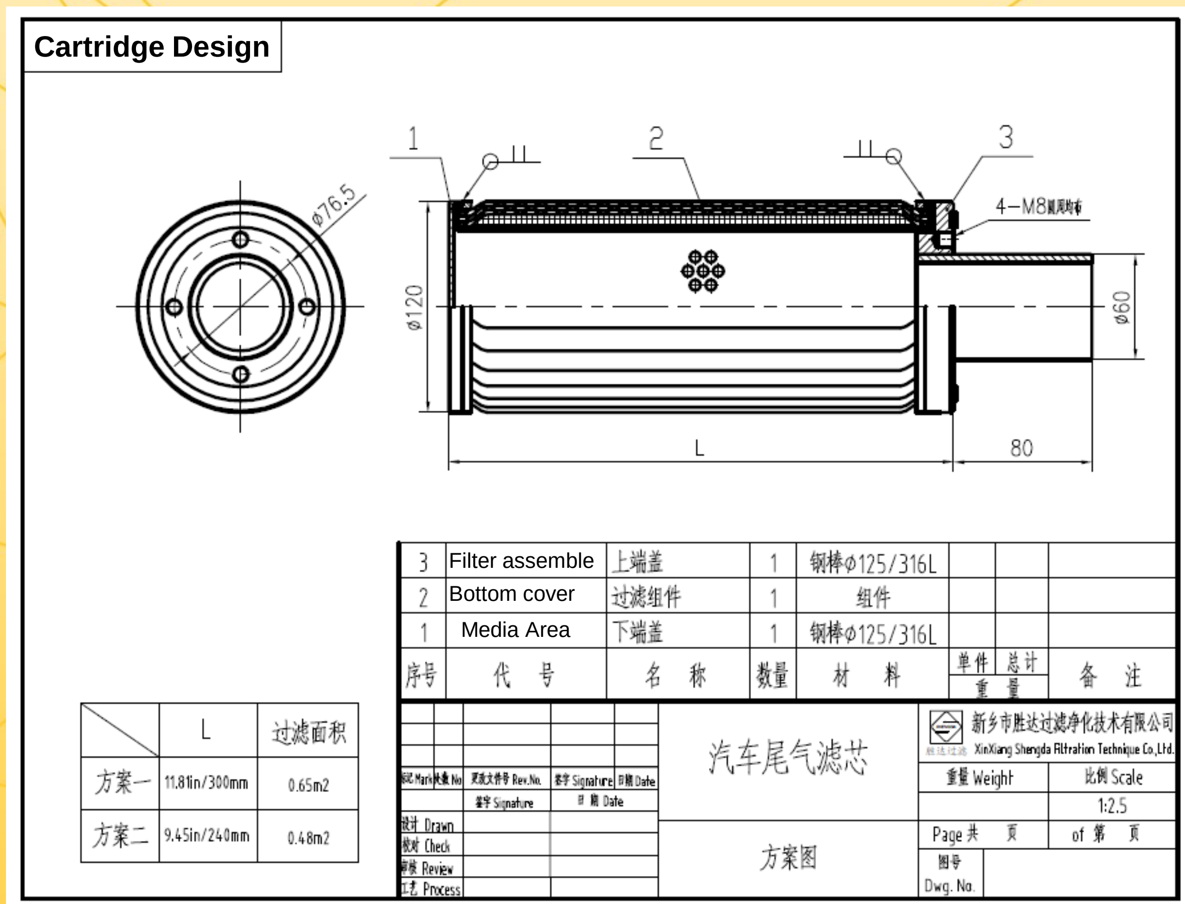
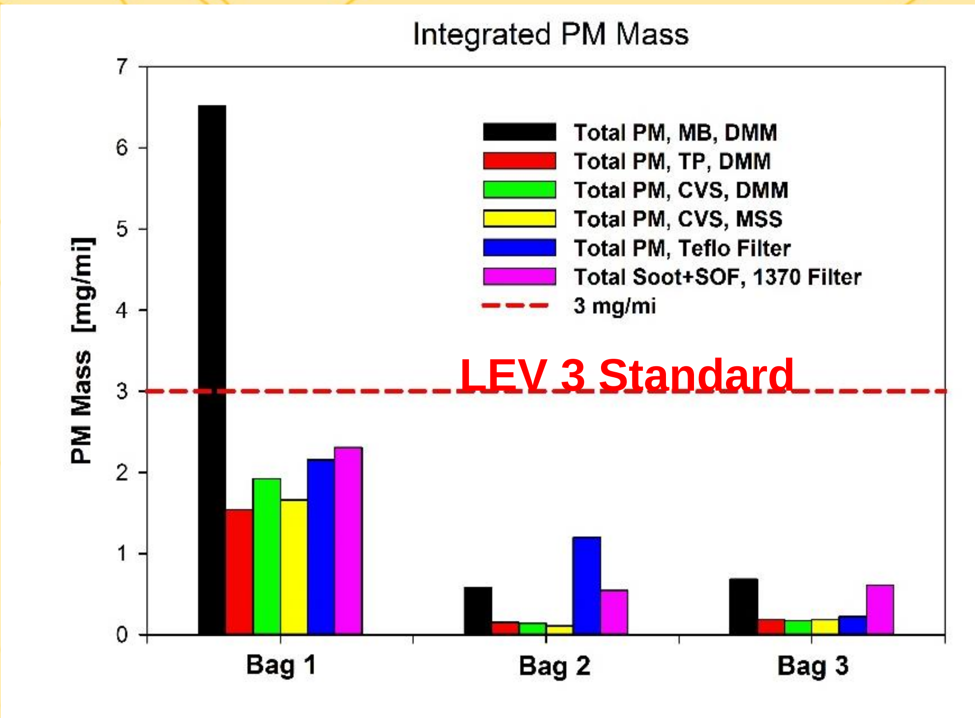
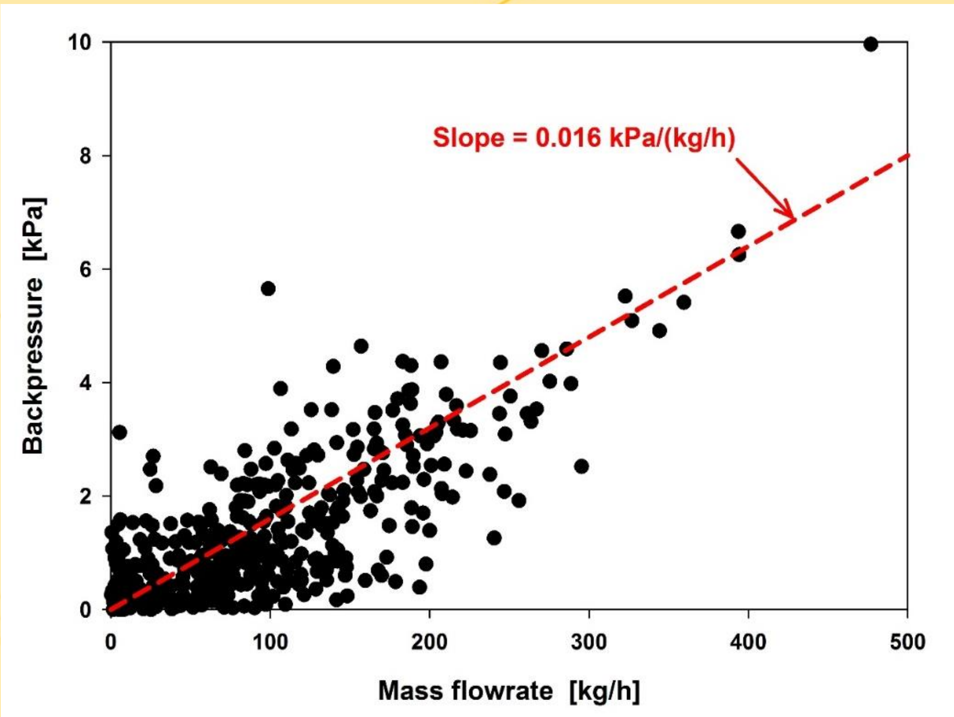
# Gasoline Particulate Filter (GPF) Prototypes




- **GPF prototypes with two media areas (0.48 and 0.65 m²) were built and their filtration performance (efficiency and back pressure) were tested.**

# Vehicle Test Results from Ford Motor (Protypes will meet 2017 Euro and US Standards)




- **Vehicle test results indicate the efficiency of the GPF prototype is greater than 70%, with an average backpressure below 2 kPa for US06 drive cycle. (US06 is a high speed drive cycle with high exhaust flowrate and temperature, which is typically associated with high backpressure.)**

UMN Patent Pending

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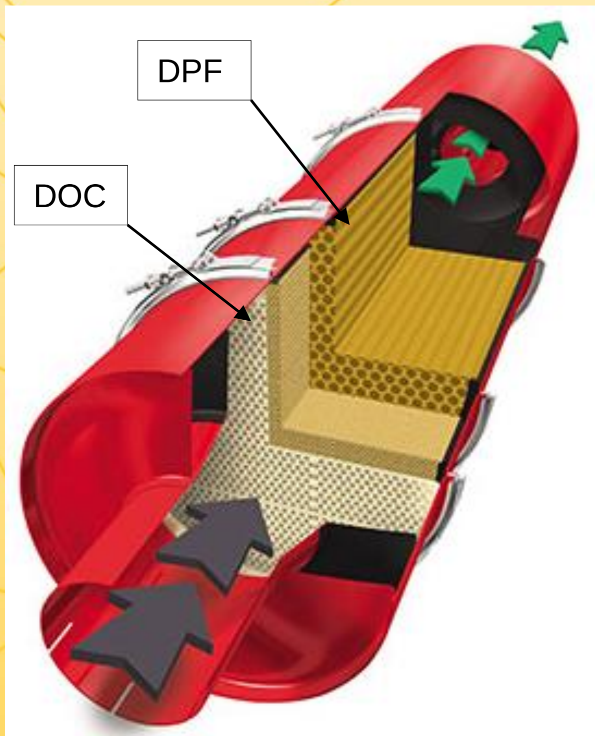
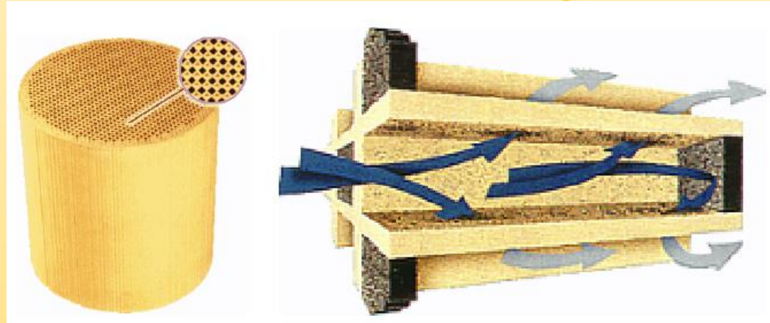
# Diesel Particulate Filter (DPF) reduces the emission of Particulate Matter (PM) from diesel engine



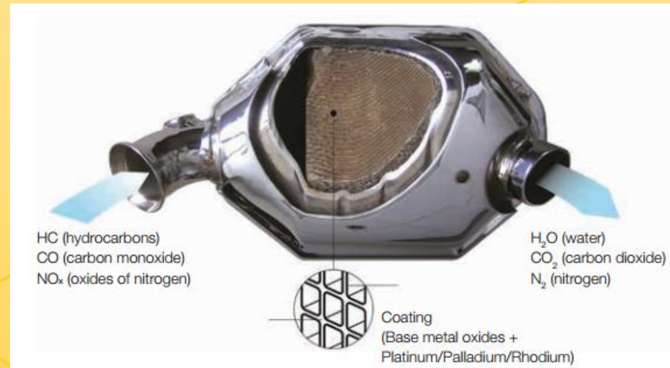

Courtesy of Cummins Filtration

Diesel Particulate Filter （DPF）



Courtesy of Corning and Johnson-Matthey

Diesel Oxidation Catalyst （DOC）




Courtesy of BASF

- Most high efficiency DPFs use wall flow filter, as shown in top right image.
- Without regenerative unit to oxidize soot, the DPF can be clogged quickly.

**Passive regeneration**——Use Diesel Oxidation Catalyst (DOC) before DPF to oxidize the NO in the exhaust to $NO_2$.

**Active regeneration**——Inject extra fuel before DPF, or use catalyst from fuel.

**Off-board regeneration**——Filter is removed, and then burned or electrically heated.

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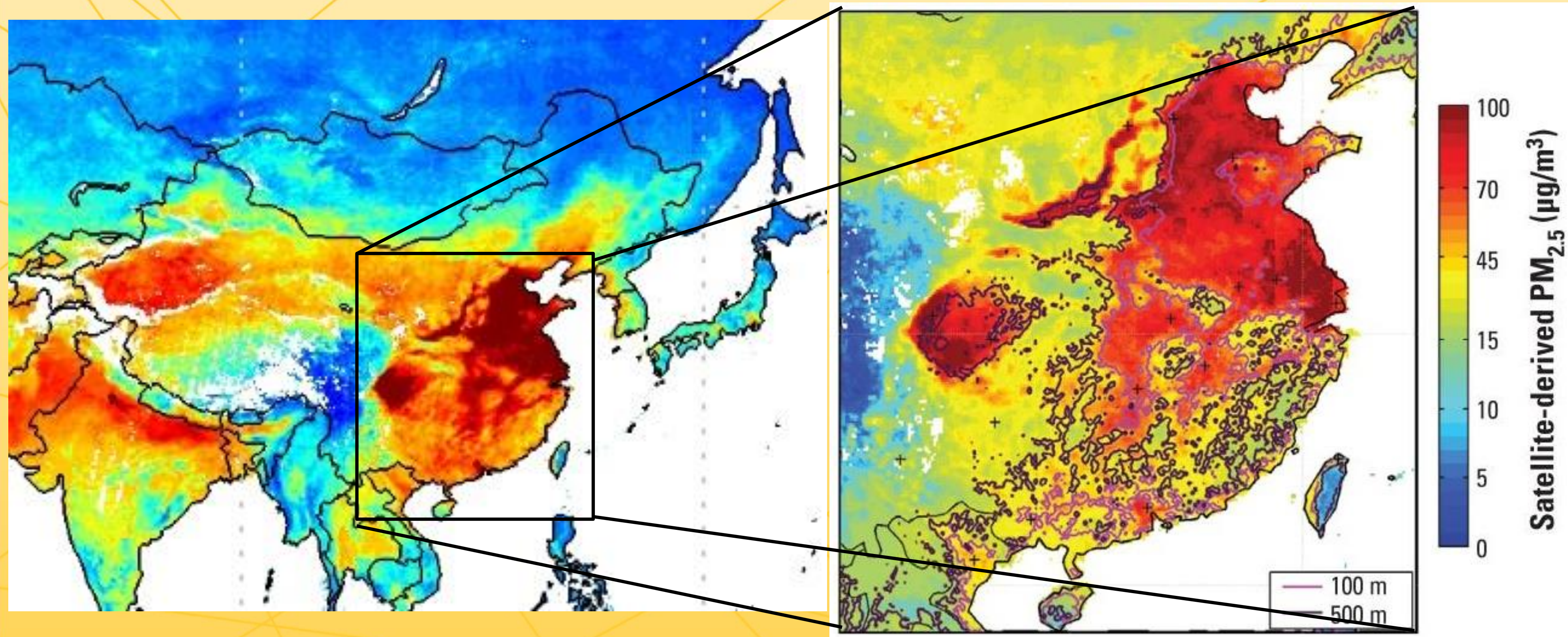
# PM$_{2.5}$ Pollution and Haze Formation in China




- **600 million Chinese (50% of the population) and 25 provinces (25% of the land area) are being affected**
- **WHO Global Burden of Disease (GBD) estimated the outdoor air pollution has resulted in 1.2 million premature deaths each year in China.**

van Donkelaar et al., *Environ Health Perspect* 2010;118:847-855

# China Tackles $PM_{2.5}$

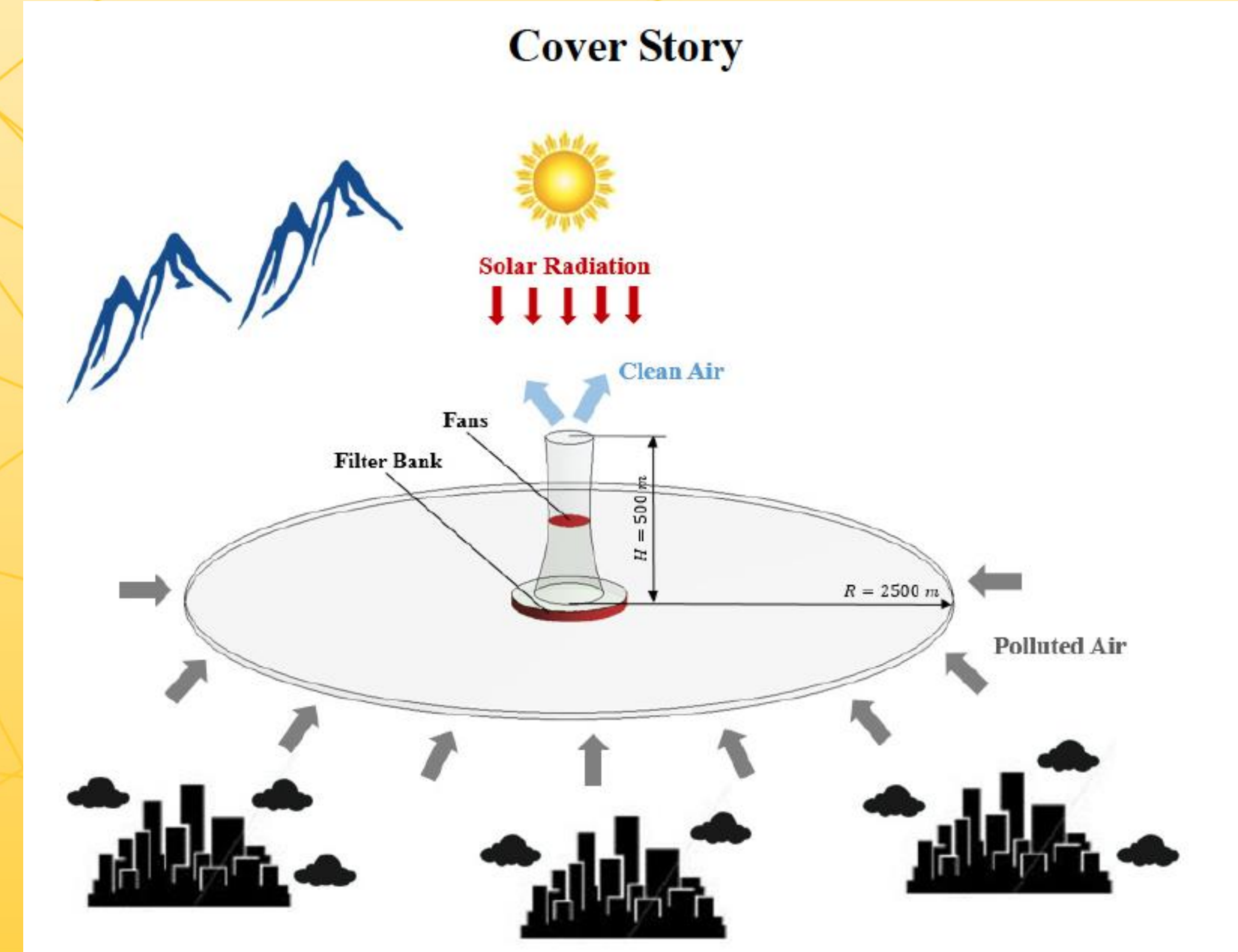
- In September, 2013, the first National Action Plan on Air Pollution Prevention and Control (2013–17), requires that annual PM2.5 in the Beijing-Tianjin-Hebei Area, Yangtze River Delta, and Pearl River Delta should be reduced by over 25%, 20%, and 15%, respectively, by 2017 compared with 2012, and that the annual PM2.5 in Beijing should be controlled at 60 μg/m³ in 2017.
- The National Action Plan requires that US$277.5 billion be invested over the next 5 years in the prevention and control of air pollution.

*Reference: Zhu CHEN et al., “China Tackles Health Effects of Air Pollution,” Lancet Vol. 382, December 14, 2013, www.thelancet.com*

# UMN and CFR Ready to Join the Efforts

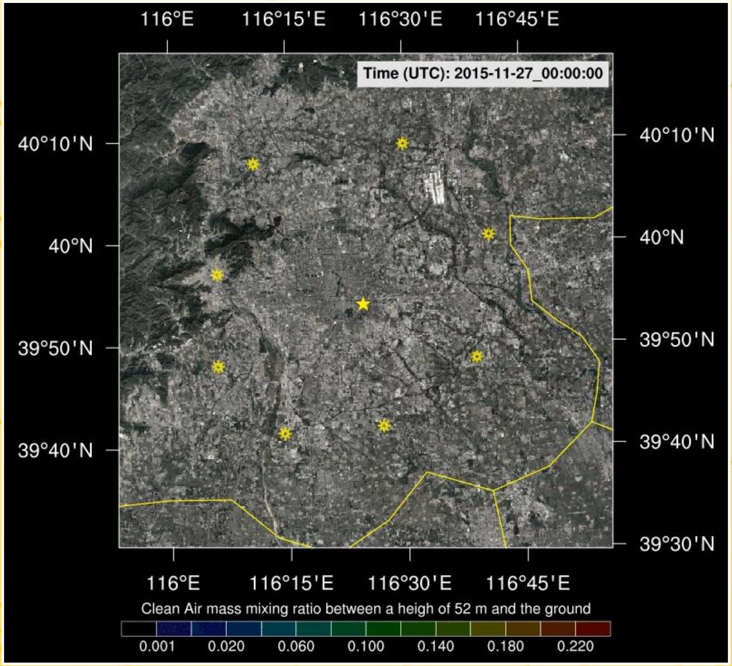
- President Kaler and CSE Dean Crouch led a delegation of 15 UMN faculty members from Science and Engineering, Medical School, and School of Public to Xi’an for a Bilateral Seminar/Workshop with the Chinese Academy of Sciences to establish research collaborations.
- Center for Filtration Research (CFR) with 30 CFR delegates from 9 companies addressed control technology at the Workshop.

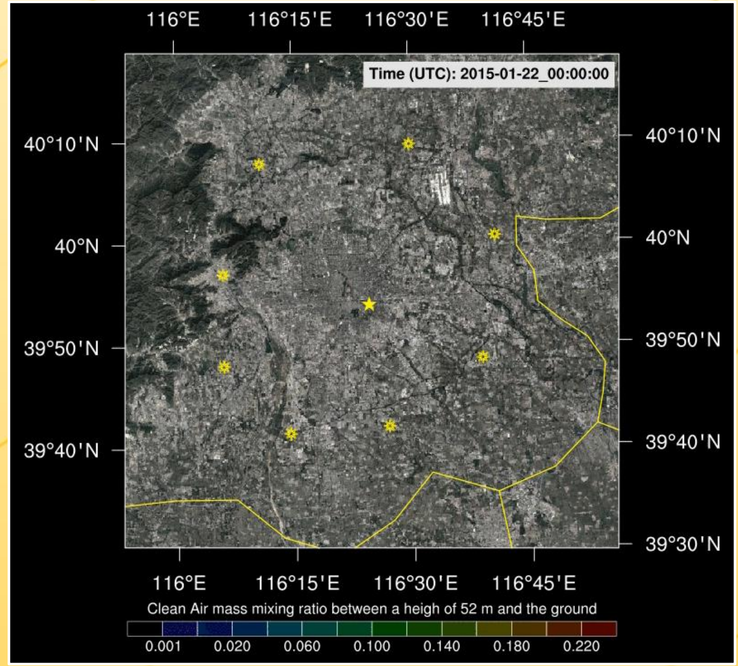
# Solar-Assisted Large-Scale Cleaning System (SALSCS) -- Disruptive Innovation

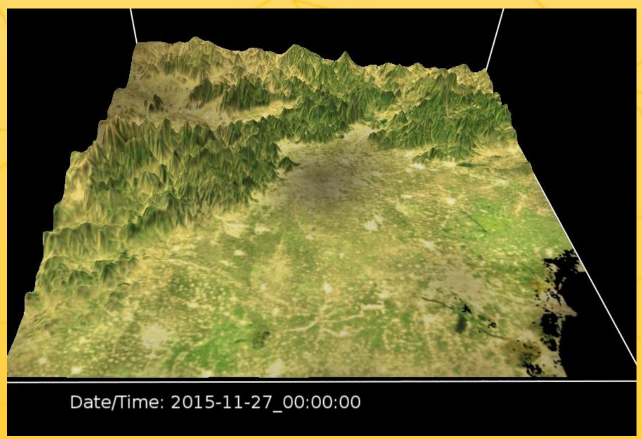


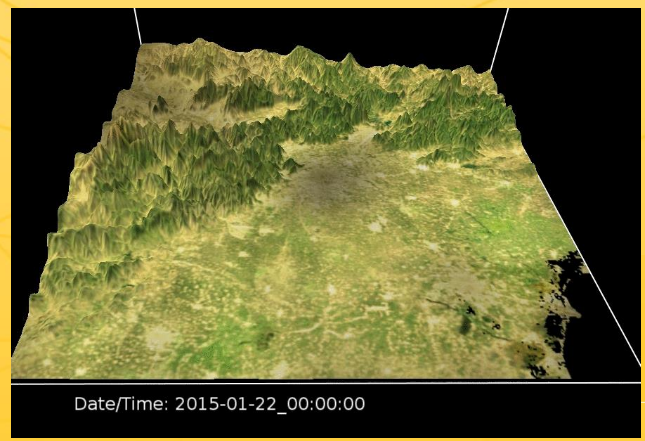

(Cao, Q.F., Pui, D.Y.H. and Lipiński, W. (2015). A Concept of a Novel Solar-Assisted Large-Scale Cleaning System (SALSCS) for Urban Air Remediation. *Aerosol Air Qual. Res.* 15: 1–10)

# Clean Air from 8 Giant SALSCS bathing Beijing Basin



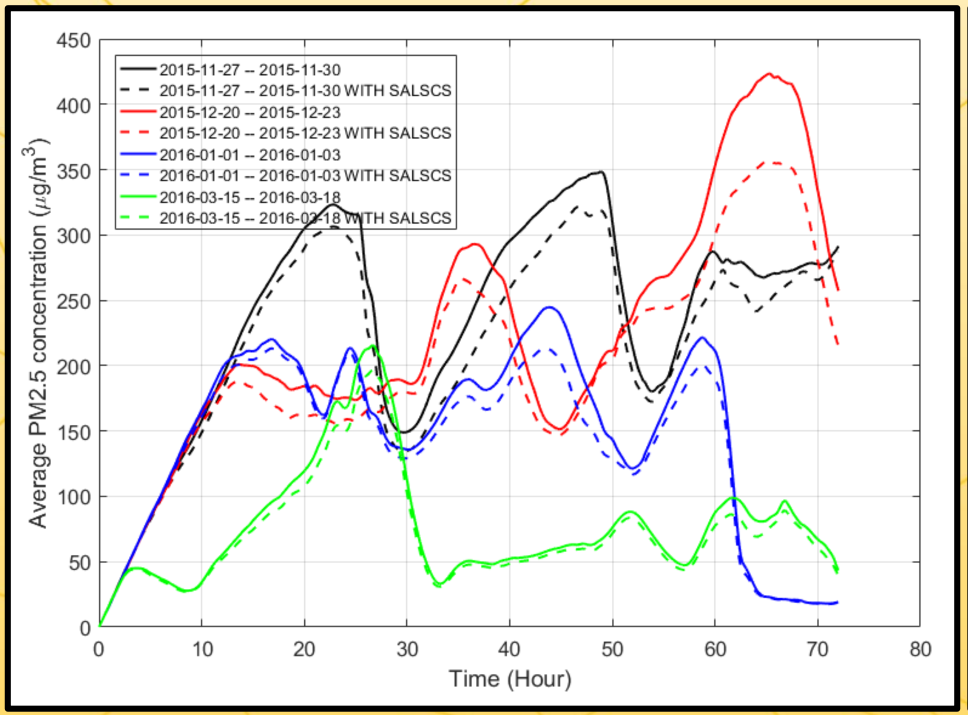



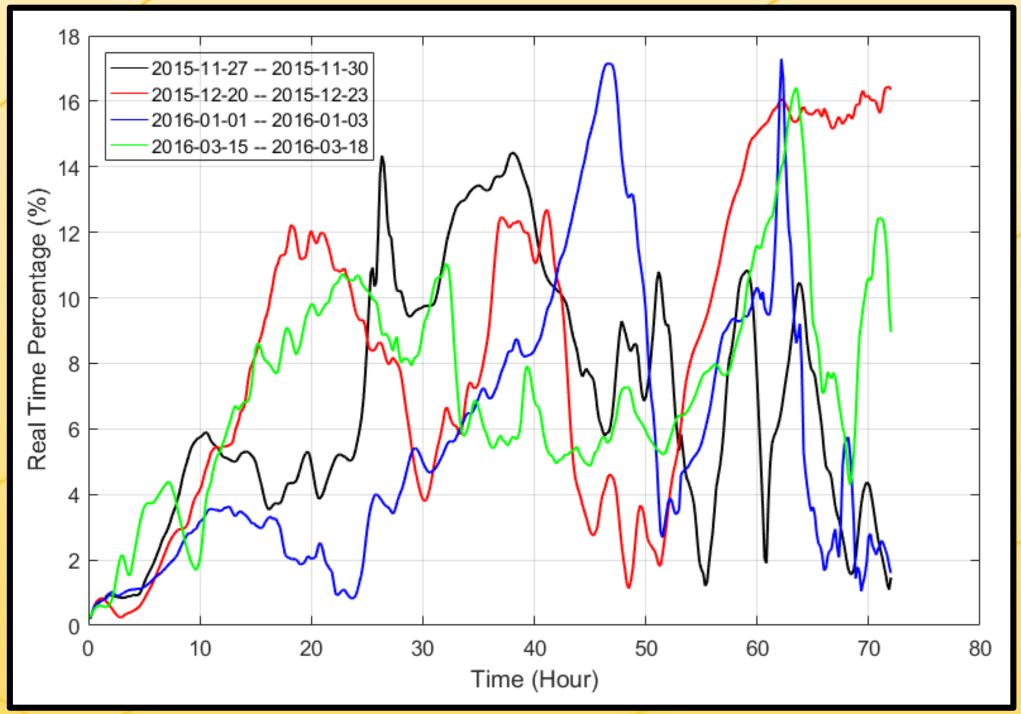




Cao, Q., L. Shen, S.C. Chen and D.Y.H. Pui, *Science of the Total Environment* 626(2018)134-146.

# Modeling Results of Air Pollutants




Average $PM_{2.5}$ concentration within a 61 km X 61 km area.




Real time percentage by comparing the conditions of WITH and WITHOUT SALSCS.

- After installing 8 full-scale SALSCS next to the 6th Ring Road of the Beijing city, we can reduce the PM2.5 concentration up to **15%** in average for the urban area of Beijing.
- This conclusion is based on our atmospheric simulation performed by the WRF model.

Cao, Q., L. Shen, S.C. Chen and D.Y.H. Pui, *Science of the Total Environment* 626(2018)134-146

Xi’an SALSCS Completed： July 22, 2016

*In collaboration with:*

Prof. Junji Cao, Institute of Earth Environment (IEECAS)

Prof. W.Q. Tao, Xi’an Jiaotong University (XJTU)

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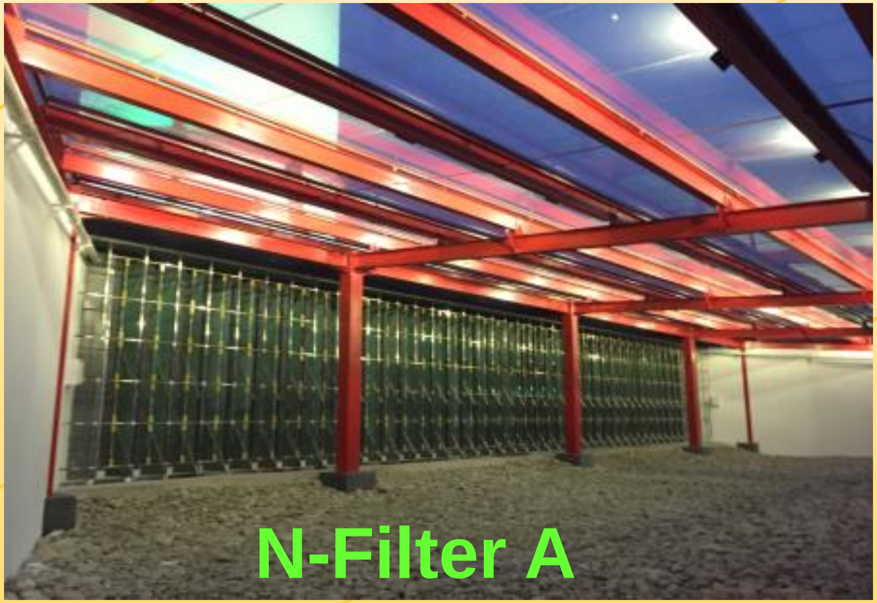
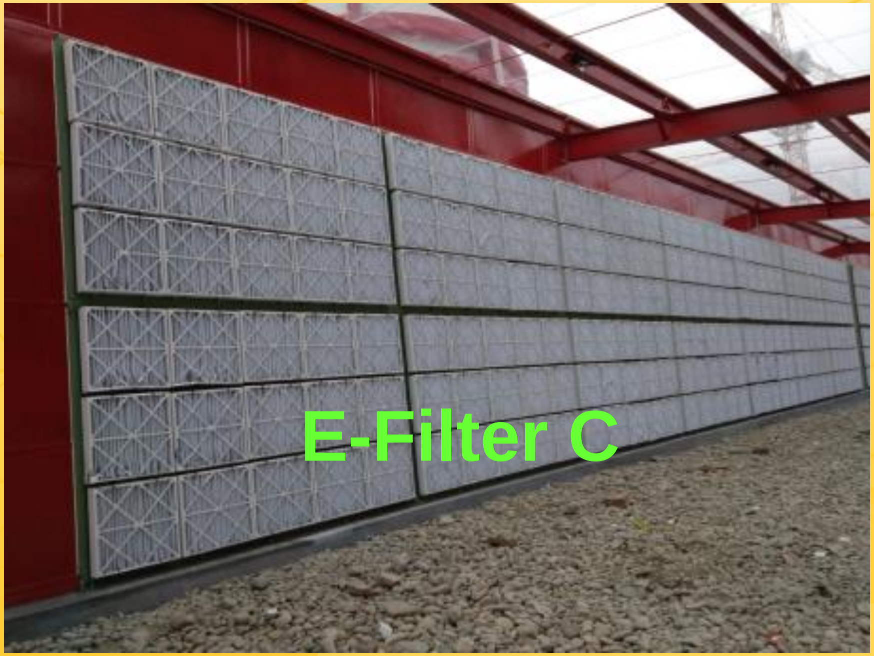
# Photos of the three filtration systems







# Flow Rate Comparison Between Measurement and Numerical Results

| *A comparison of the flow rate and temperature between the measurement and simulation* | | Time of mea | Radiation Intensity Received by Solar Collector ($W/m^2$) | Ambient Temperature ($^oC$) | Flow rate ($m^3/s$) | Temperature at the mid-way interface ($^oC$) | Temperature at the door ($^oC$) |
|---|---|---|---|---|---|---|---|
| Only one section opened | South Side (Open Section) | Jan 13<br>**2:52 pm – 3:56 pm** | **100.94** | **9.5506** | **27.46**<br>**28.97** | **14.41**<br>**10.85** | **11.14**<br>**11.09** |
| | South Side (Open Section) | Jan 13<br>**10:10 am – 11:00 am** | **166.23** | **3.8847** | **34.48**<br>**34.53** | **6.85**<br>**5.52** | **5.52**<br>**6.17** |
| | North Side *** (HAF Section) | Jan 13<br>**11:10 am – 11:51 am** | **246.93** | **6.5956** | **13.95**<br>**35.80** | **6.42**<br>**9.10** | **6.58**<br>**9.89** |
| Both the two sections opened | South Side (Open Section) | Jan 11<br>**11:17 am – 12:10 pm** | **108.68** | **4.5912** | **34.87**<br>**31.05** | **6.61**<br>**5.79** | **5.62**<br>**6.26** |
| | South Side (Open Section) | Jan 12<br>**10:48 am – 12:20 pm** | **262.68** | **6.7730** | **38.97**<br>**41.06** | **11.52**<br>**8.99** | **8.66**<br>**9.86** |
| | North Side *** (HAF Section) | | | | **20.63**<br>**30.34** | **8.41**<br>**9.92** | **7.76**<br>**10.72** |
| | South Side (Open Section) | Jan 13<br>**4:03 pm – 5:08 pm** | **33.35** | **9.0318** | **21.89**<br>**21.58** | **12.21**<br>**9.57** | **10.55**<br>**9.79** |
| | North Side (HAF Section) | | | | **10.81**<br>**11.38** | **8.80**<br>**10.08** | **9.08**<br>**10.33** |

- Red color indicating simulation results and blue color indicating measurement results.
- The flow rates matches each other well, except for the two cases indicated by the red asterisks.
- This discrepancy is caused by the fact that the real solar energy received by the north section is much smaller than the radiation intensity measured by the weather station.

Cao, Q., L. Shen, J. Cao, D.Y.H. Pui, et al., submitted to *Renewable & Sustainable Energy Reviews* (2018)


西安除霾塔

South China Morning Post | CHINA HK ASIA WORLD COMMENT BUSINESS TECH LIFE CULTURE SP

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NOW READING

China builds 'world's biggest air purifier' ... and it

# China builds 'world's biggest air purifier' ... and it seems to be working

A 100-metre high air purification tower in Xian in Shaanxi province has helped reduce smog levels in the city, preliminary results suggest

PUBLISHED : Tuesday, 16 January, 2018, 6:45am
UPDATED : Tuesday, 16 January, 2018, 6:45am

COMMENTS: 5

- Two dozens of Newspaper articles and TV News
- Nature (March 6, 2018) "China Tests Giant Air Cleaner to Combat Smog"
- UK Chief Medical Officer (CMO) Annual Report (March 9, 2018)
- NBC Universal and Digital Trend (March, 2018)

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  - SALSCS (3rd Gen) for Green Community

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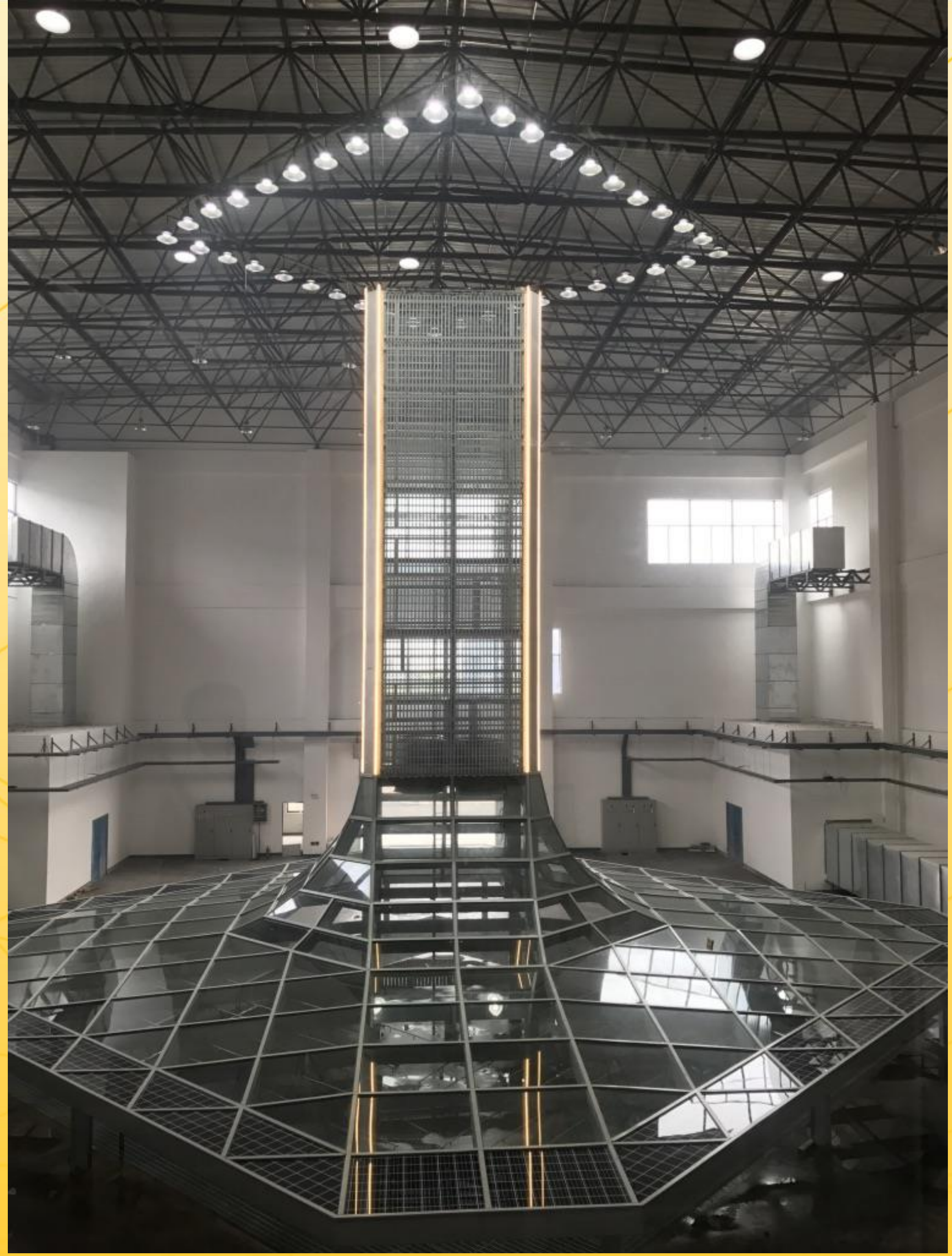

Vice Minister Wang of China Environmental Protection
Ministry review the SALSCS on September 25, 2017

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**2nd Generation SALSCS in City**

# Health Effects of Climate Change

- Climate Change
  - Temperature Rise
  - Sea Level Rise
  - Hydrologic Extremes
    - Droughts
    - Floods
    - Fires

- Health Effects
  - Urban Heat Island Effect → Heat Stress, Heart Attacks
  - Air Pollution & Aeroallergens → Respiratory Diseases
  - Vector-borne Diseases → Malaria, Dengue, Zika
  - Water-borne Diseases → Cholera, Cryptosporidiosis
  - Water Resources & Food → Malnutrition, Diarrhea
  - Mental Health & Refugees → Migration, Overcrowding

- Cost of Cleaner Energy

  < \$30 / $tCO_2$

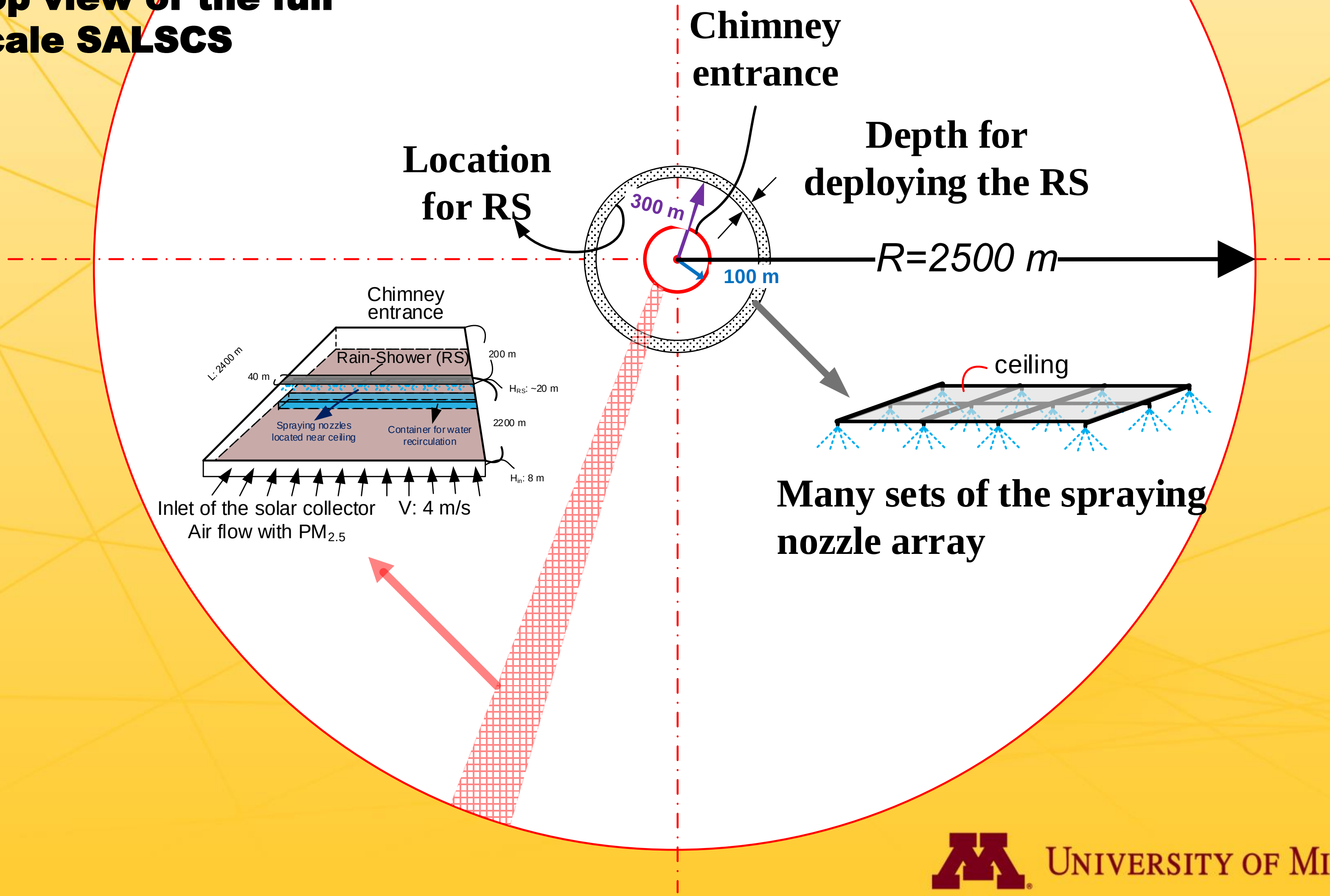
Benefits of Cleaner Energy

\$200 / $tCO_2$

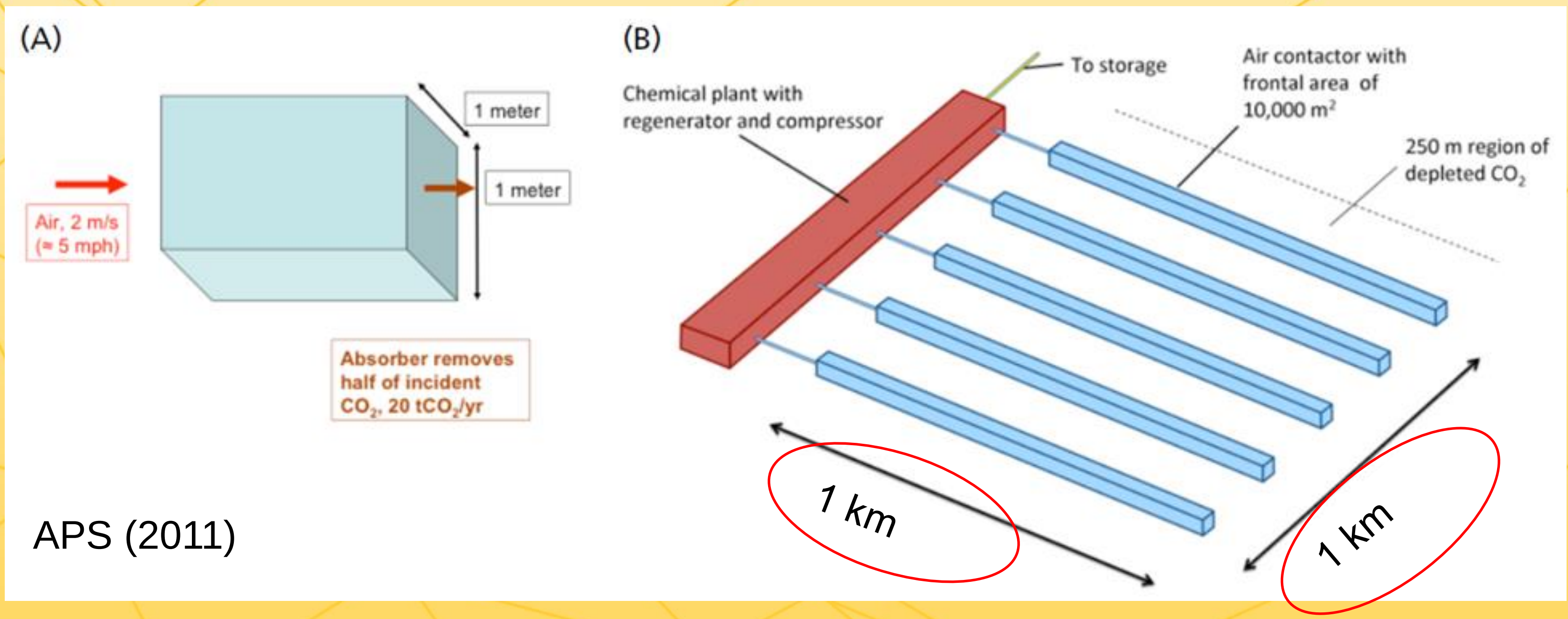
Patz (2017), West (2013)

# $2^{nd}$ Generation SALSCS with Water Spray – Low cost and effective way to collect $PM_{2.5}$ and $CO_2$ (using NaOH spray)

**Top view of the full scale SALSCS**



# $CO_2$ removal by the APS unit (a facility proposed by the American Physical Society)




- APS claims one of this facility can have a removal rate of 1 $MtCO_2$/yr based on the assumption of 50% $CO_2$ removal efficiency.
- Contact Column using NaOH solution to absorb CO2 was applied. This will cause a great deal of pressure drop and require a lot of fan power.

It also needs a lot of fans to draw air into the unit.

# Economics Comparison of $CO_2$ removal by the Water-Spray SALSCS and APS unit

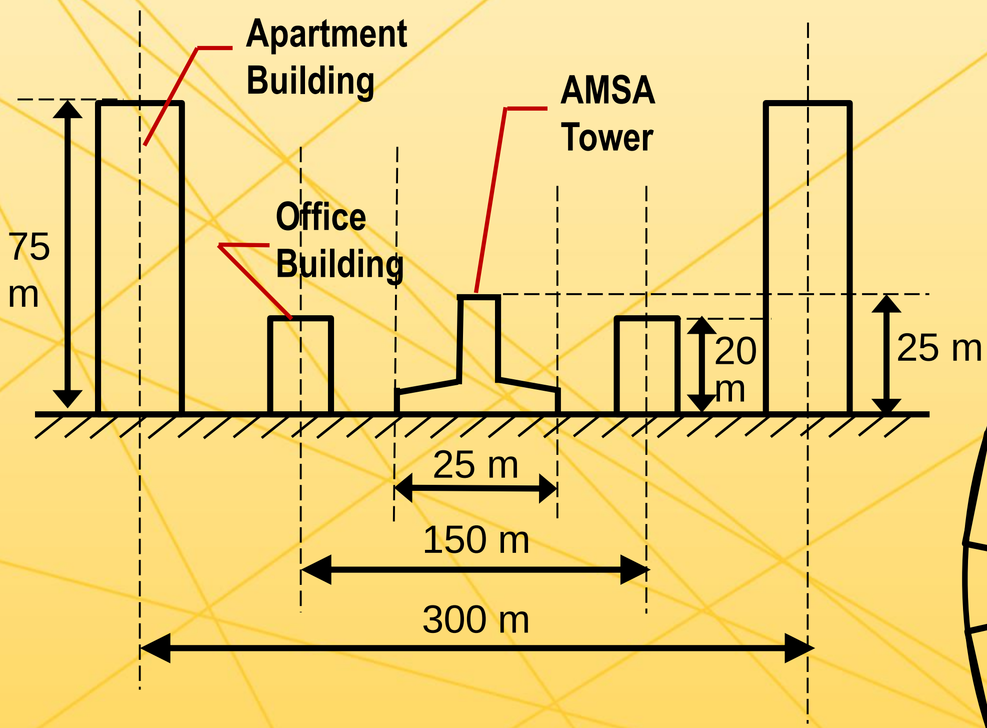
1. **80 APS units per year** need to be built continuously for 100 years to reduce **$CO_2$ concentration from the current 390 ppm to 340 ppm in 100 years**.

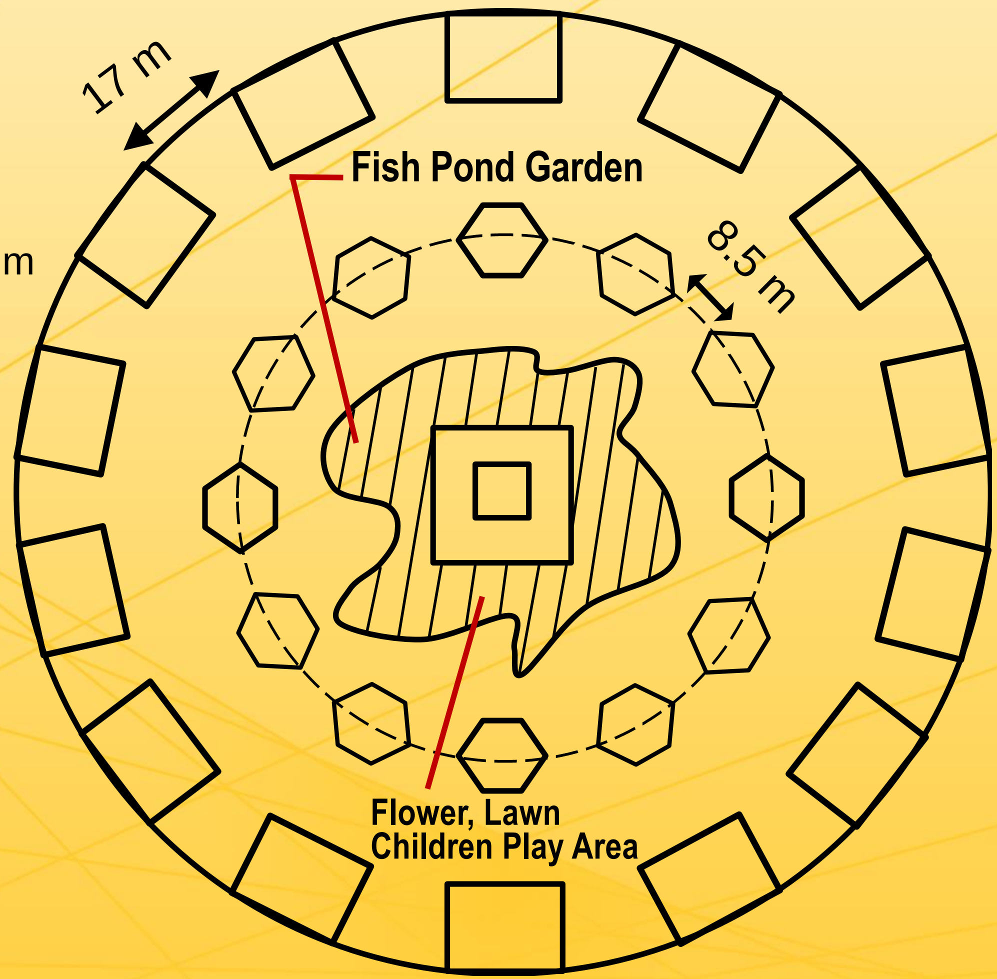
2. The **Water-Spray SALSCS** has more **than four times capacity** of $CO_2$ removal **than the APS unit** (2x higher flowrate and 2x contact efficiency) meaning that only **20 SALSCS need to be installed per year around the world.**

3. The proposed 8 SALSCS units built in Beijing will remove 40% of the APS global requirement. (China contributes about 30% of global $CO_2$.)

3. The capital cost is already paid for by PM2.5 removal. The **operating cost is estimated to be about 1/10 of APS unit** – making it **feasible to install** such units around the world.

# SALSCS (3rd Gen) Green Community



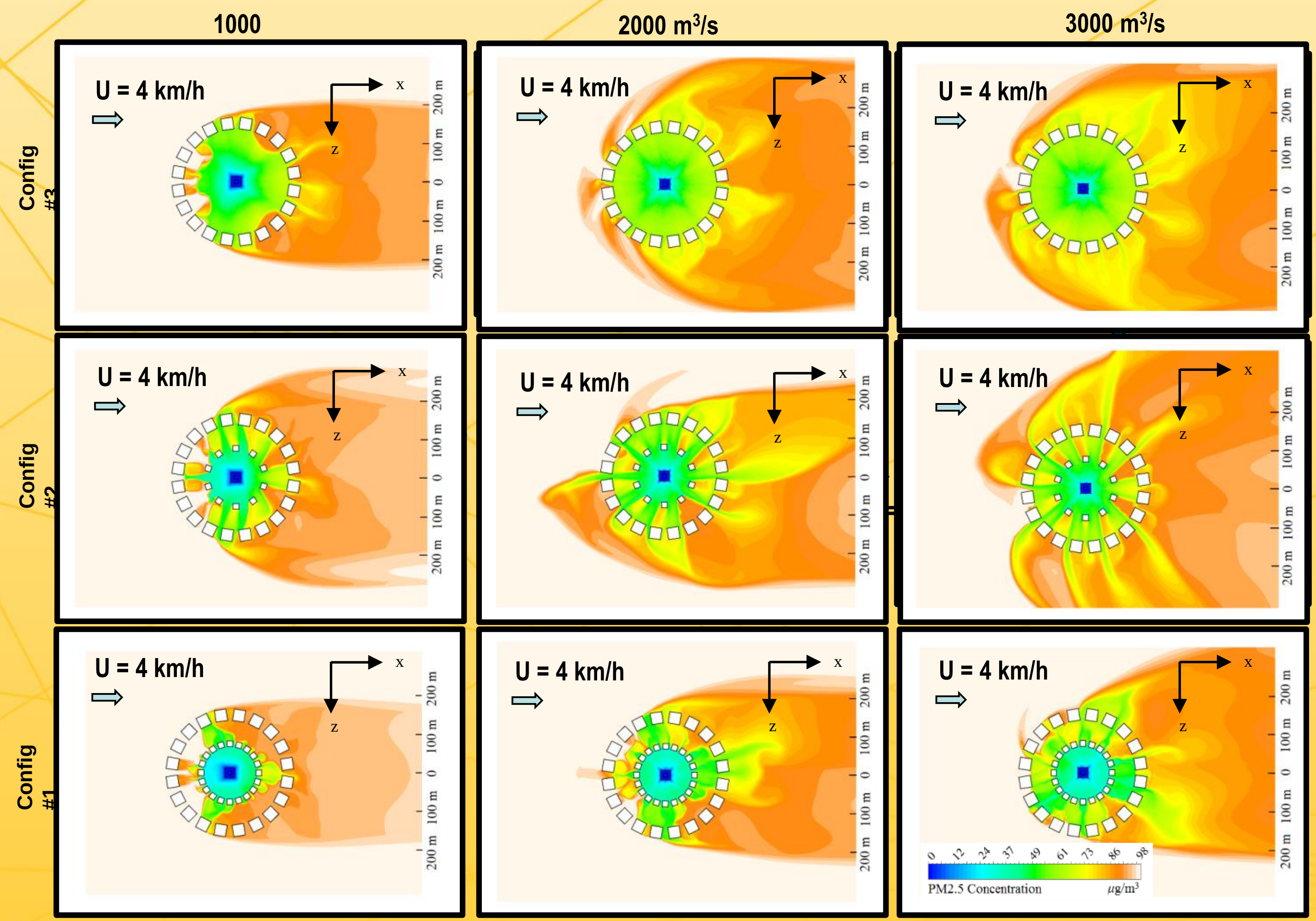

- Air exchange rate:

$$= \frac{control\ volume}{clean\ air\ \ flow\ rate}$$

$$= \frac{75\,m \times 300\,m \times 300\,m \times \pi / 4}{2000\,m^3/\sec}$$

$$= 2650 \sec = 45 \min$$

# Contours of $PM_{2.5}$ Concentration: A Comparison

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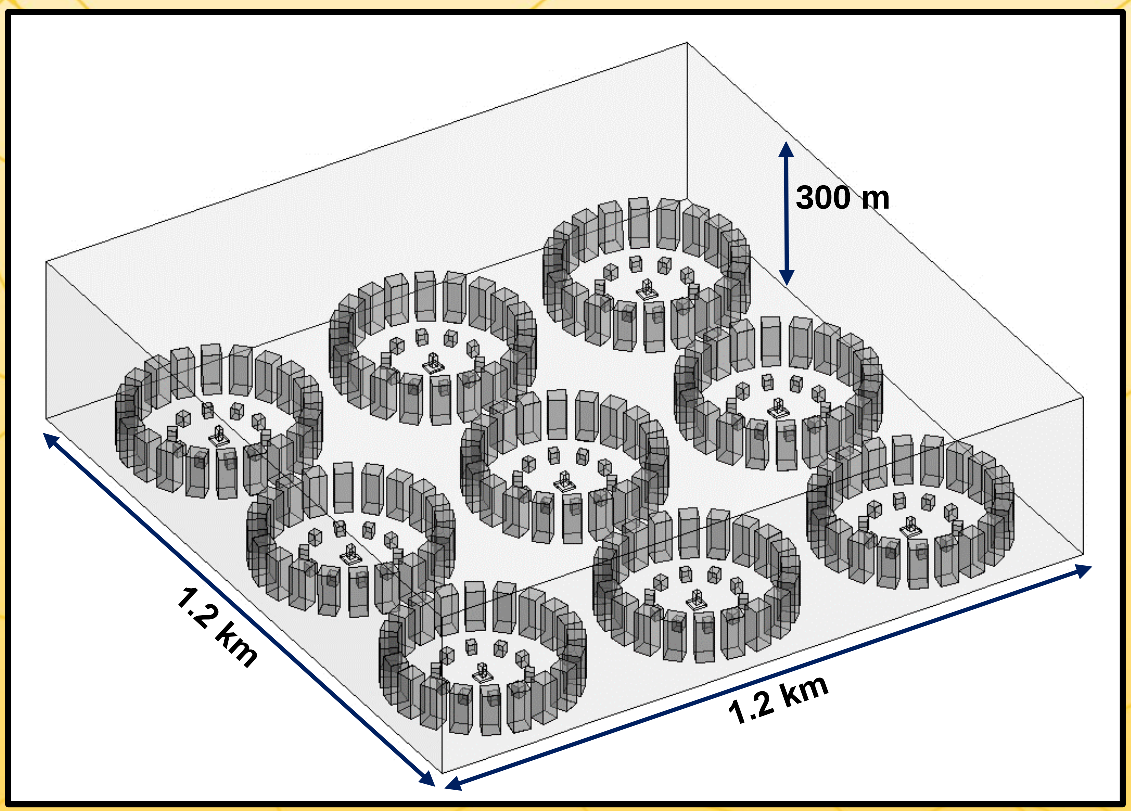
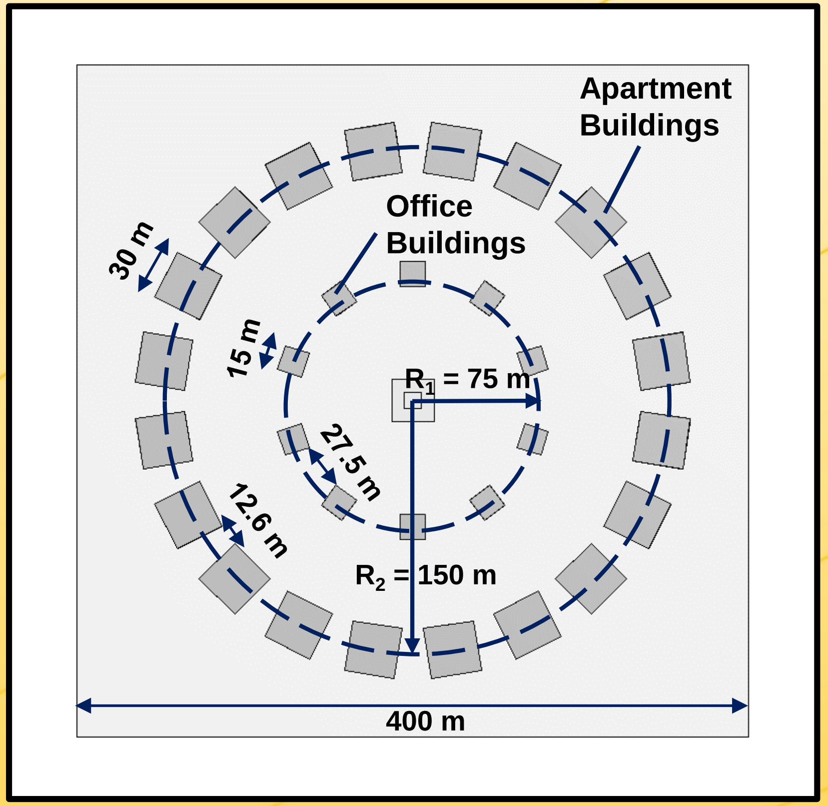
# 9-Clusters of SALSCS Green Community




A cluster of AMSA green community




Computational domain

- The AMSA has a tower of 25 m in height. The tower has a dimension of 10 m.
- The base of the system has a horizontal dimension of $25 \times 25$ m$^2$ with a height of 4 m.
- The office and apartment buildings are 20 m and 75 m tall, respectively.
- There are 20 apartment buildings for each community. The number of office buildings will be 20, 10 or 0.
- **The 9 clusters together can house 75,000 residents inside the green community.**

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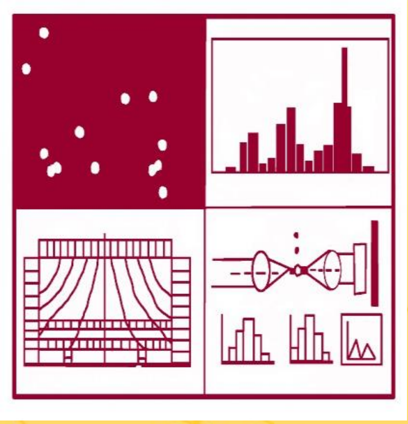
# Aerosol and Particle Measurement Short Course



## August 20-22, 2018

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Minneapolis, MN

www.cce.umn.edu/aerosol

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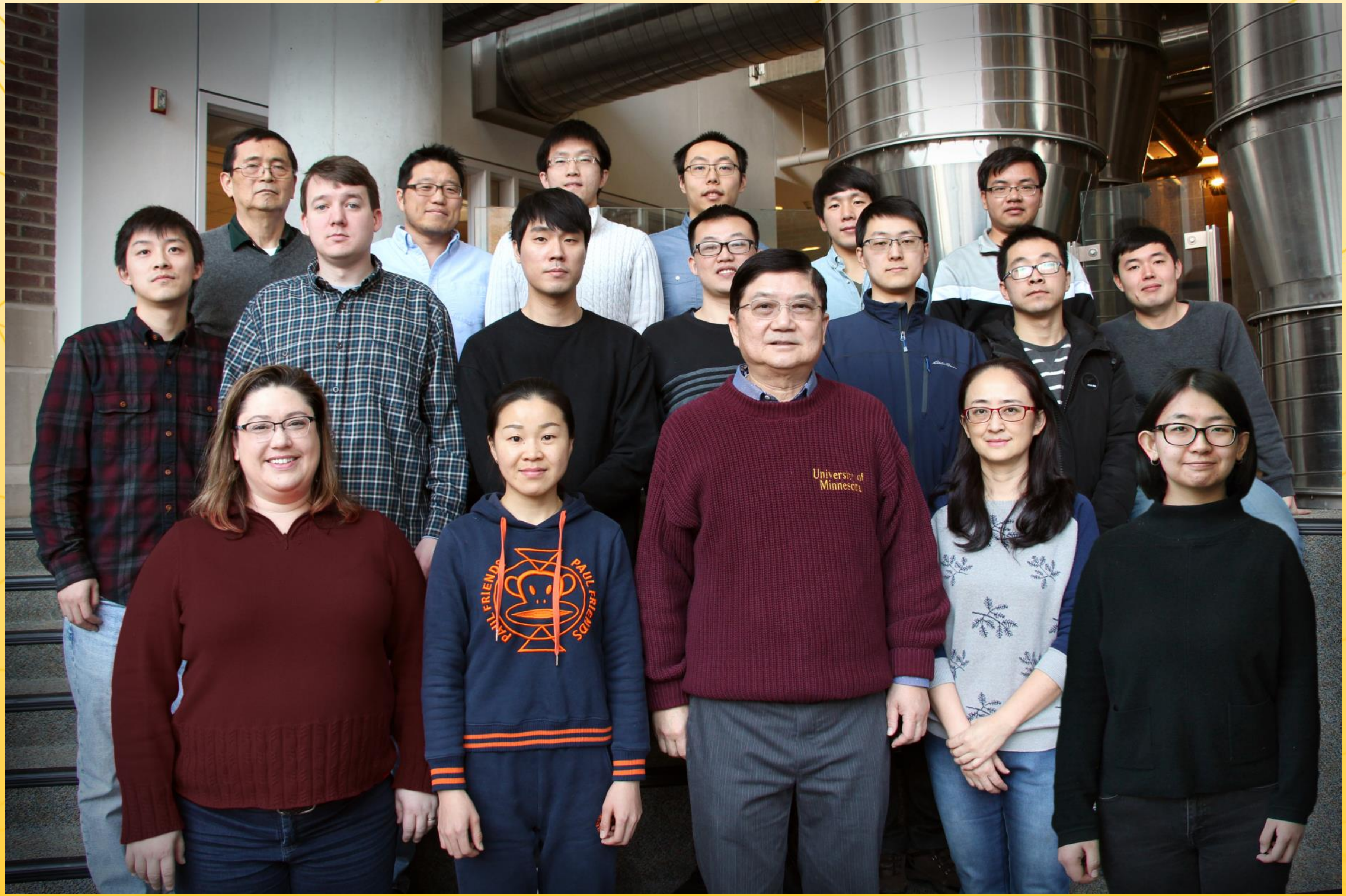
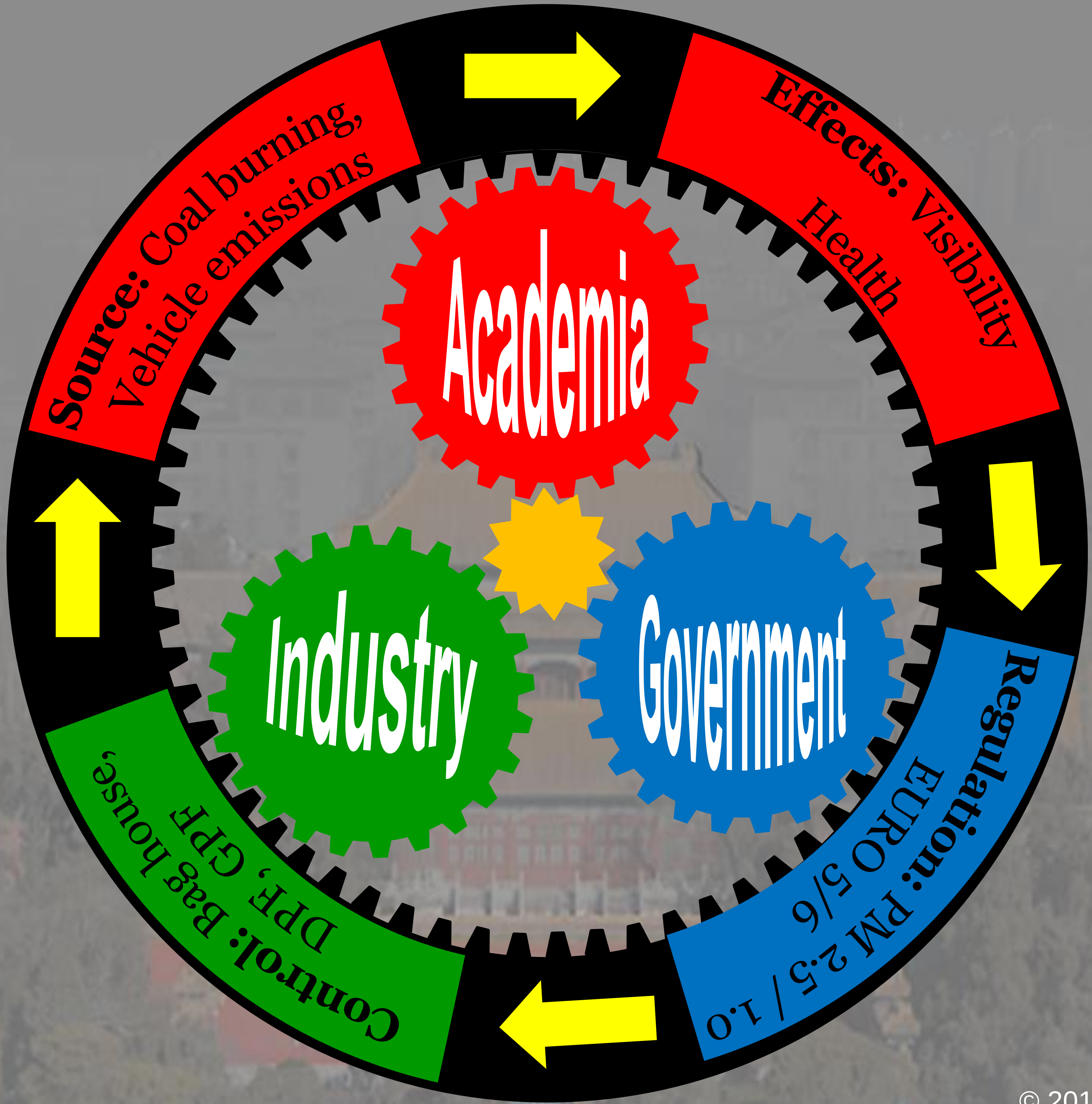



UNIVERSITY OF MINNESOTA



Source: Coal burning, Vehicle emissions
Effects: Visibility
Health
Regulation: PM 2.5 / 1.0
EURO 5/6
Control: Bag house,
DPF, GPF
Academia
Industry
Government