Catalytic Ozonation: A Promising Technology for Removal of VOCs from Air

Presented by:

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Presentation Overview

- Introduction to air pollution
- Outdoor air pollution
- VOCs emission in Canada
- Indoor air pollution
- Key impact of air pollution
- Our research & findings
- Concluding remarks

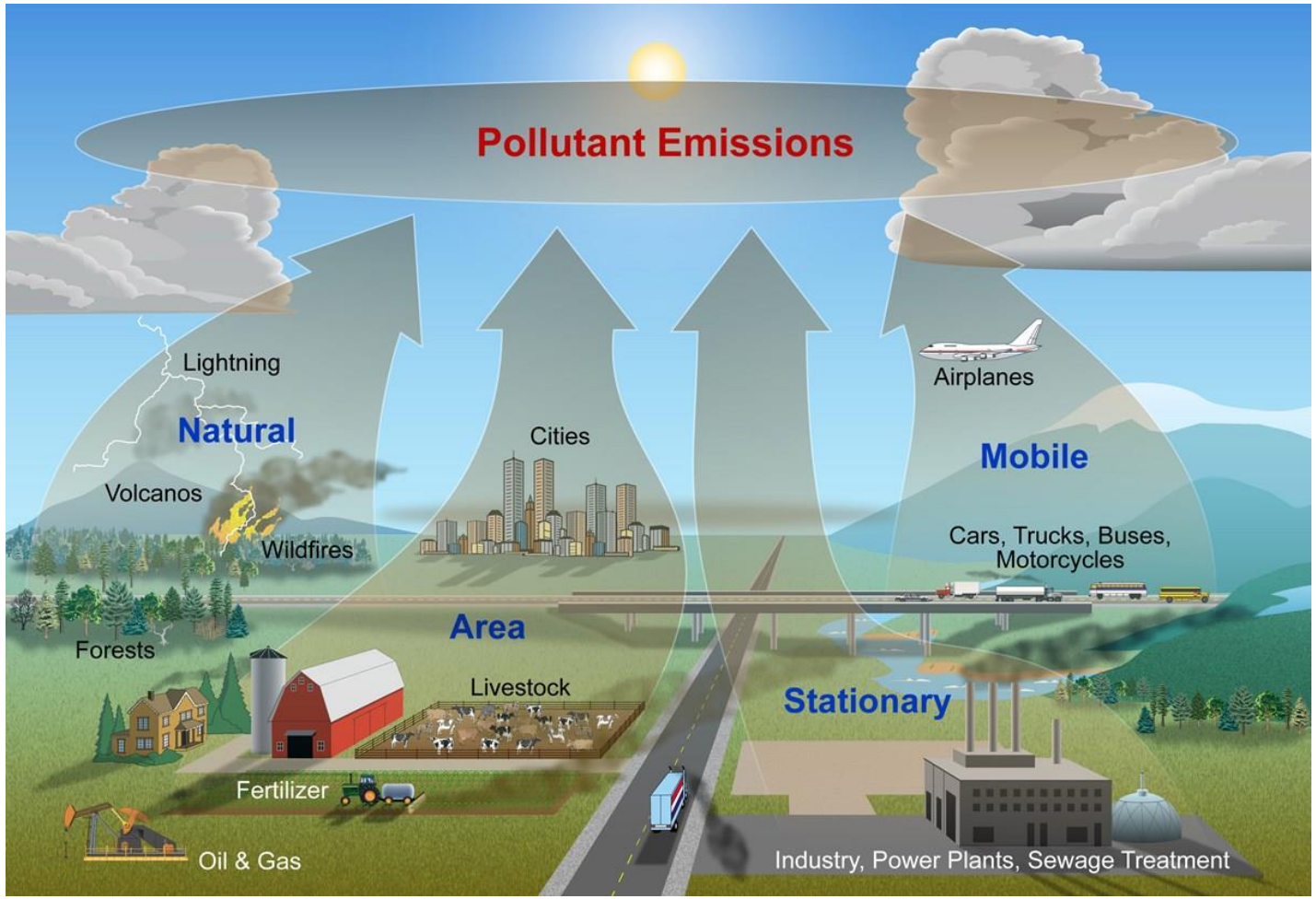
Air pollution

Any contamination that disturbs the natural composition and chemistry of air

Indoor air pollution

Outdoor air pollution

Outdoor air pollution

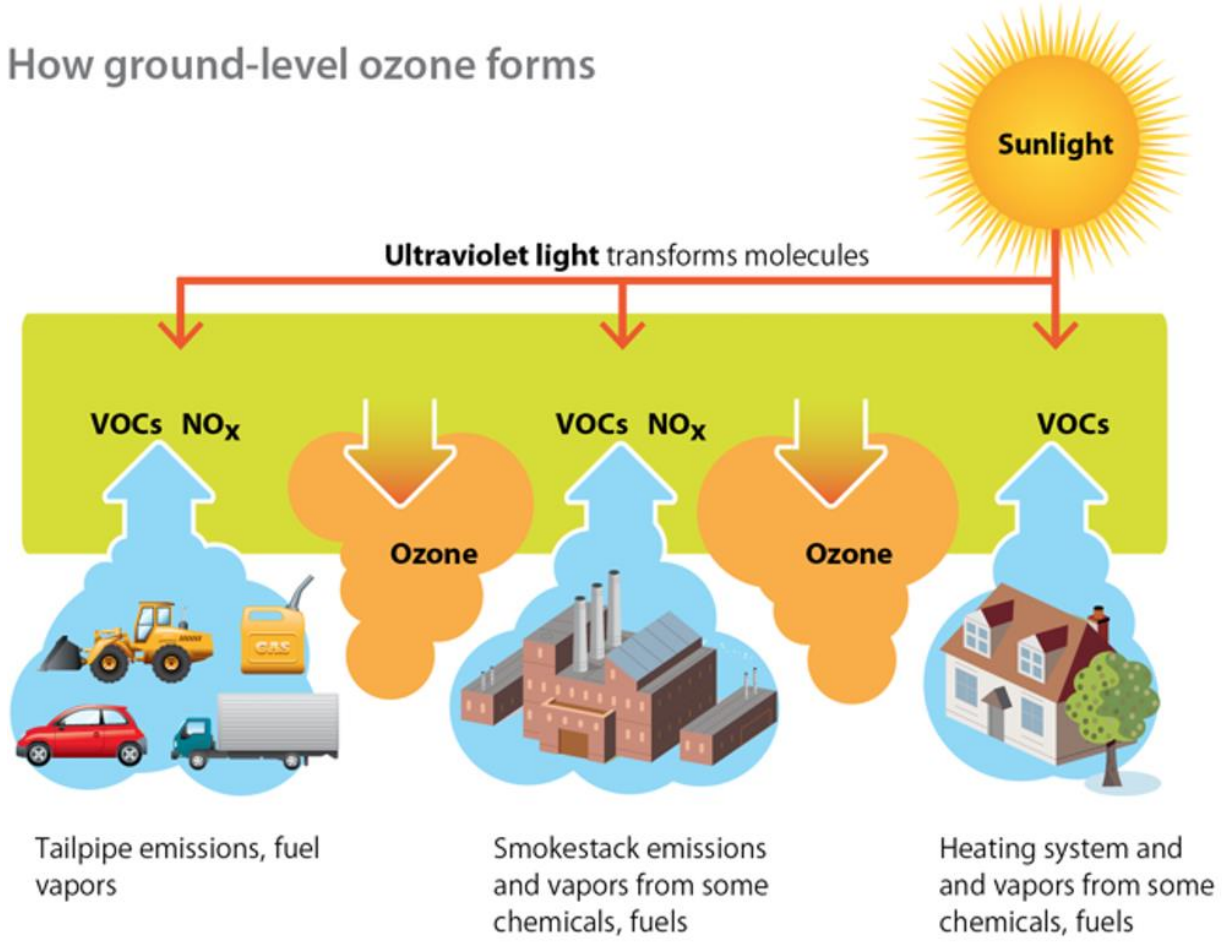


https://www.thinglink.com/scene/700851929466535937

Pollution emissions

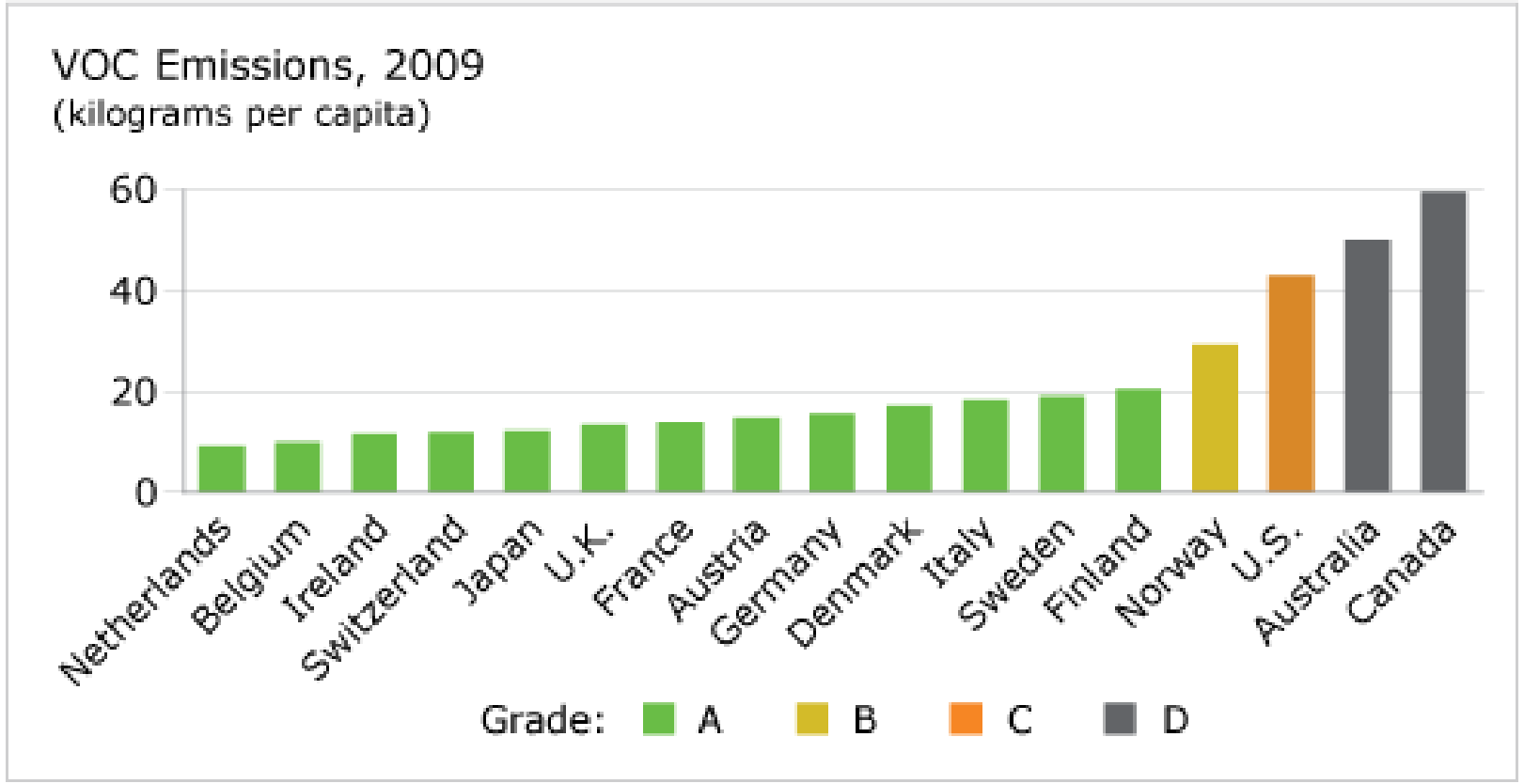
Pollutants	Sulphur oxides
	Nitrogen oxides
	Particulate matter
	Carbon monoxide
	Non-methane volatile organic compounds

How do VOCs cause smog?



https://theconversation.com/your-shampoo-hair-spray-and-skin-lotion-may-be-polluting-the-air-96088

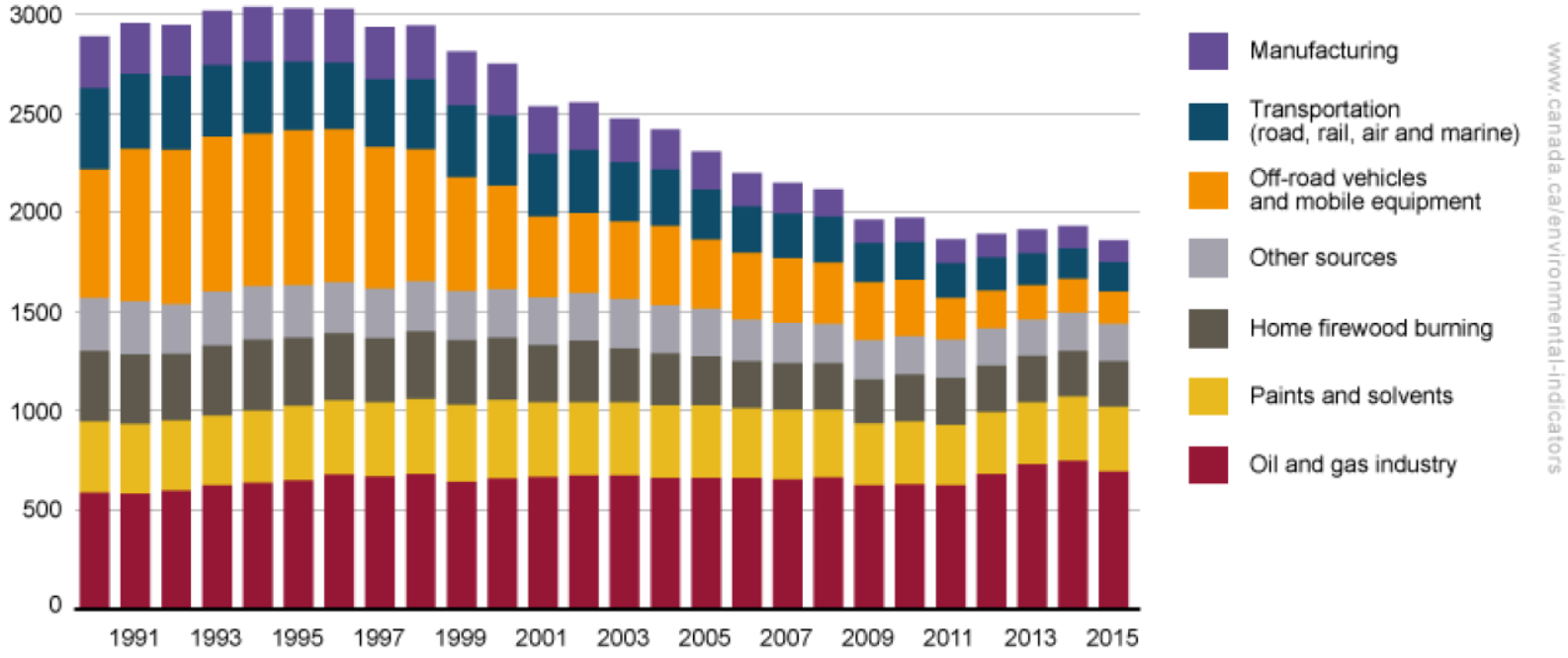
Canada VOCs emission ranking



https://www.conferenceboard.ca/hcp/Details/Environment/VOC-emissions.aspx?AspxAutoDetectCookieSupport=1

Canada VOCs emissions by source

The oil and gas industry was the main source of VOC emissions in 2015 with 693 kt emitted (37% of total emissions).



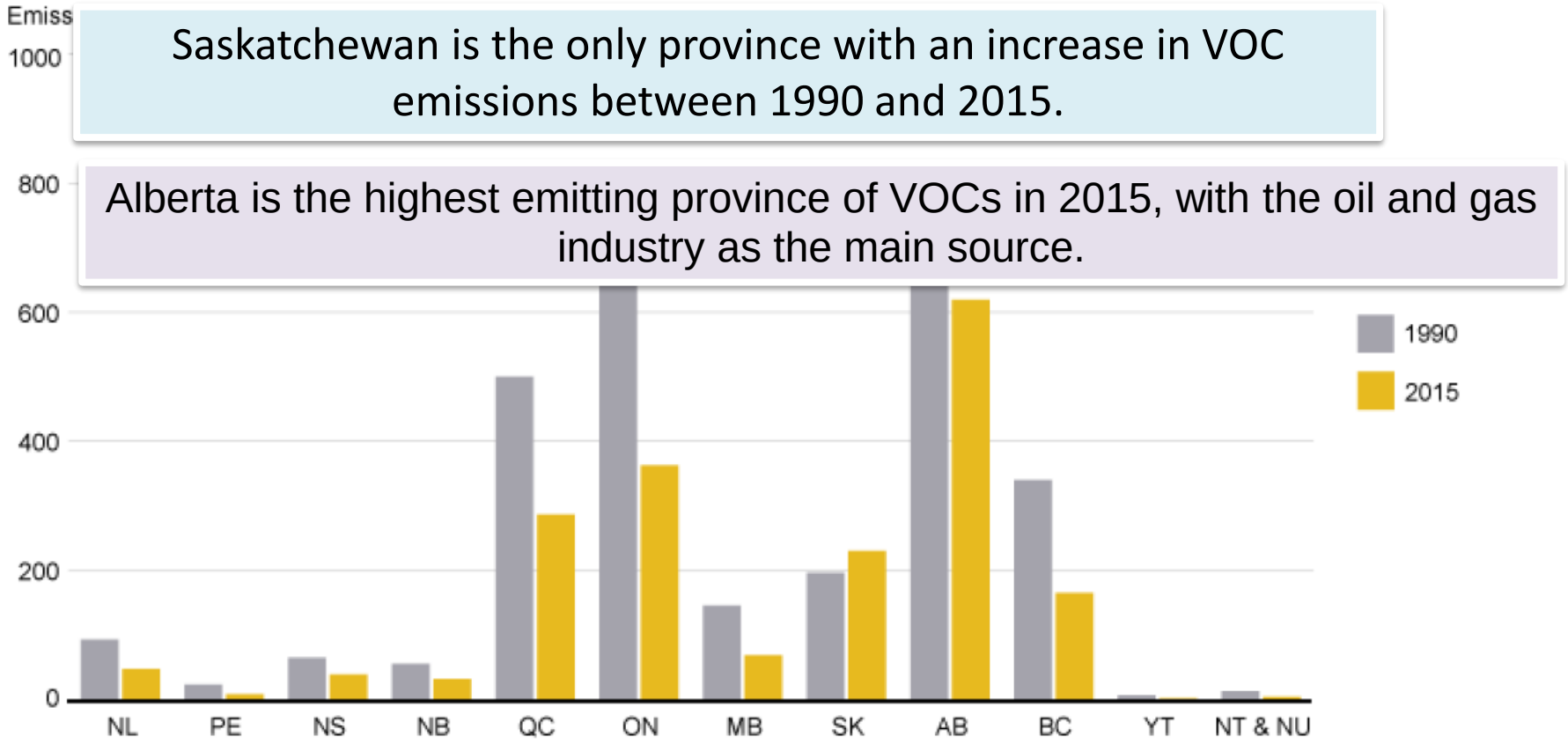
Paints and solvents and home firewood burning were also important sources contributing 18% (326 kt) and 12% (230 kt) of total emissions.

VOCs emissions by province and territory

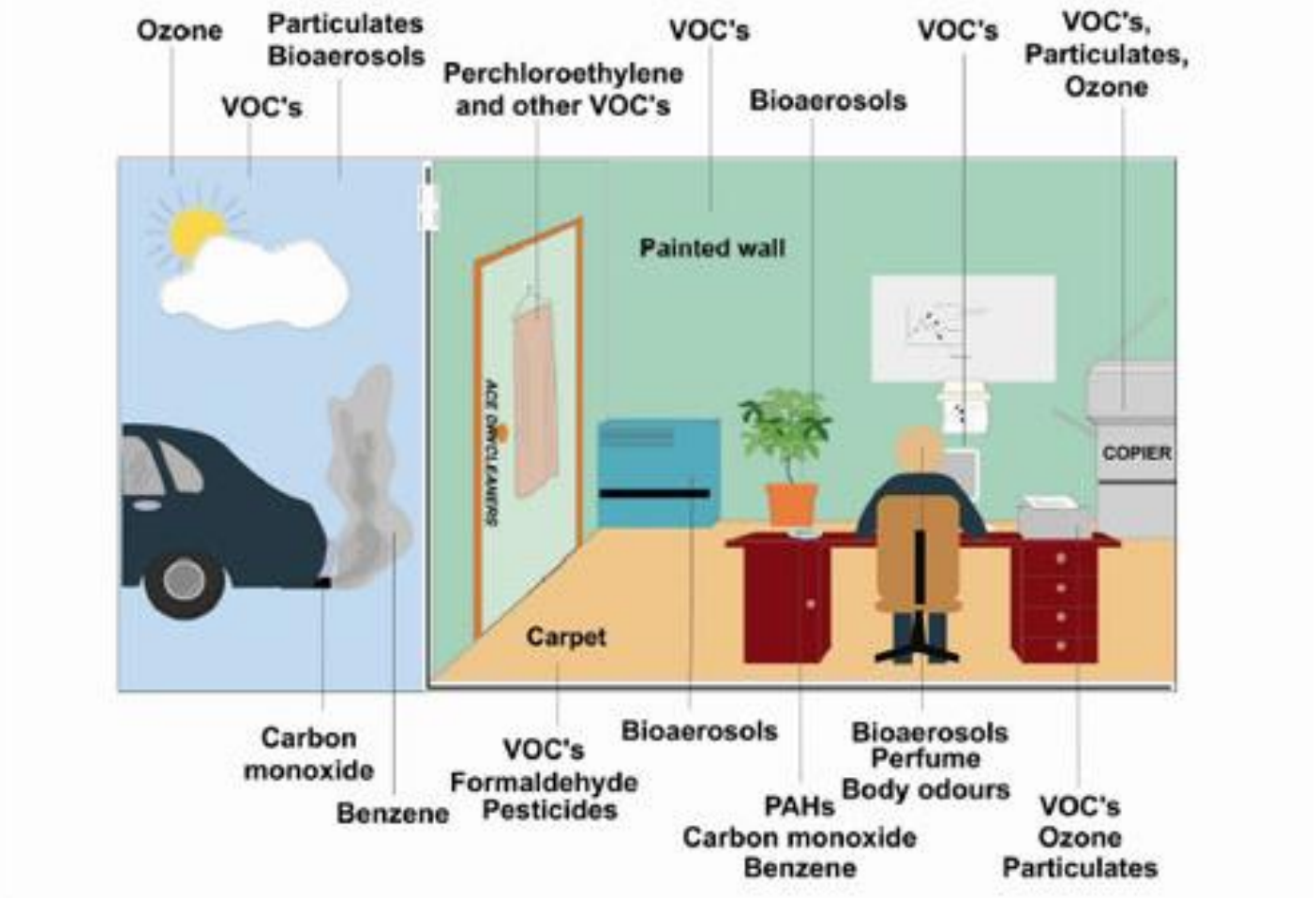
Alberta emitted 33% of national VOCs emissions.

Saskatchewan is the only province with an increase in VOC emissions between 1990 and 2015.

Alberta is the highest emitting province of VOCs in 2015, with the oil and gas industry as the main source.



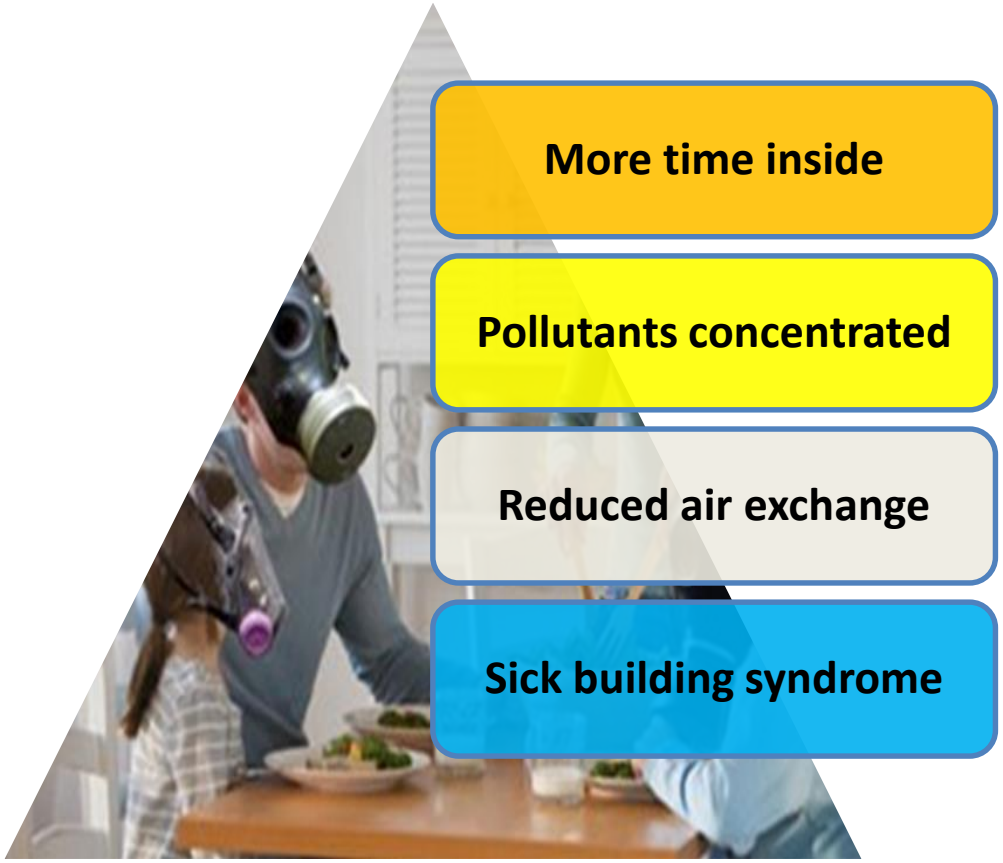
Effect on indoor air



www.construction-innovation.info/www.construction-innovation.info/index2f08.html?id=1140

Indoor air pollution

Indoor air pollution is a greater threat to humans than outdoor air pollution.



- **More time inside**
- **Pollutants concentrated**
- **Reduced air exchange**
- **Sick building syndrome**

Concentration of VOCs in indoor and outdoor air

City	Ypsilanti				Ann Arbor				Dearborn			
Indoor / Outdoor	Indoor		Outdoor		Indoor		Outdoor		Indoor		Outdoor	
Statistics	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Benzene	4.06	5.59	0.77	0.28	3.47	8.35	0.73	0.23	3.06	3.86	1.67	0.88
Toluene	28.00	33.37	1.56	0.84	15.61	30.49	1.14	1.51	14.82	29.61	4.25	2.75
p-Xylene,m-Xylene	9.77	16.43	0.83	0.41	13.89	51.67	1.59	5.07	9.01	15.44	3.22	1.99
1,2,4-Trimethylbenzene	3.71	5.16	0.29	0.14	2.29	5.81	0.21	0.15	3.59	7.53	1.10	0.69
Styrene	0.90	1.06	0.04	0.08	0.28	0.36	0.02	0.04	0.62	0.49	0.09	0.06
Naphthalene	6.16	15.64	0.14	0.10	1.68	2.49	0.38	0.77	3.34	7.88	0.42	0.23
1,4-dichlorobenzene	12.31	52.65	0.16	0.47	1.29	3.65	0.03	0.04	4.83	21.33	0.20	0.29
Chloroform	0.75	0.75	0.04	0.03	0.22	0.33	0.06	0.02	1.33	2.23	0.13	0.37
Carbontetrachloride	1.21	1.23	0.74	0.25	0.91	0.21	0.72	0.23	1.09	0.64	1.11	0.45
Trichloroethylene	0.04	0.20	0.01	0.04	0.02	0.04	0.01	0.03	0.06	0.11	0.04	0.03
Tetrachloroethene	0.46	0.49	0.19	0.24	0.65	0.85	0.22	0.18	1.28	3.82	0.56	0.45
a-Pinene	21.26	33.90	0.37	0.26	14.78	31.23	0.29	0.17	5.76	8.59	0.21	0.40
d-Limonene	17.63	11.45	0.21	0.11	10.63	16.09	0.15	0.12	37.46	44.65	1.05	2.18
n-Nonane	6.86	23.30	0.15	0.17	0.71	1.15	0.09	0.08	1.64	2.50	0.32	0.21
n-Hexadecane	0.80	0.96	0.02	0.04	0.28	0.16	0.00	0.00	0.62	0.74	0.02	0.08

Concentration unit (μg m^{-3})

C Jia, S Batterman, C Godwin and G Hatzivasilis, Proceedings: Indoor Air, 2005, 2630-2634

What's in indoor air?

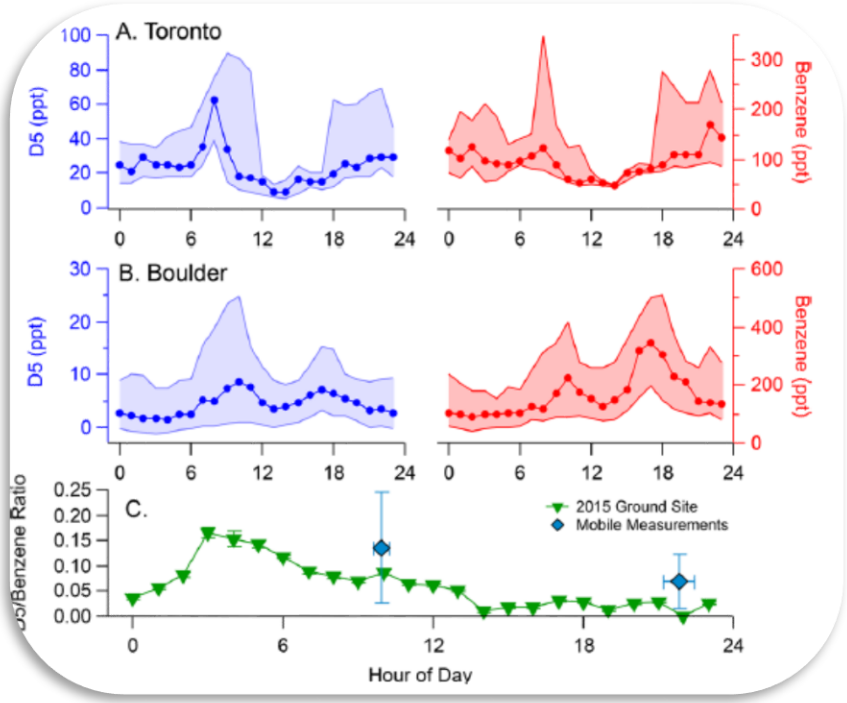
Airborne particles	**Diesel exhaust, carbon black, dust, smoke, fibers, plant, matter, hair, pollen**
Household odours and gases	**pet, smells, cigarette, smoke, chemicals, sink or drain smells**
Volatile Organic Compounds (VOCs)	**Paints, glues, varnishes, cleaning supplies, furniture, vehicle exhaust, cigarette**
Microorganisms	**Bacteria, mould (fungi), yeasts, mites and virus**

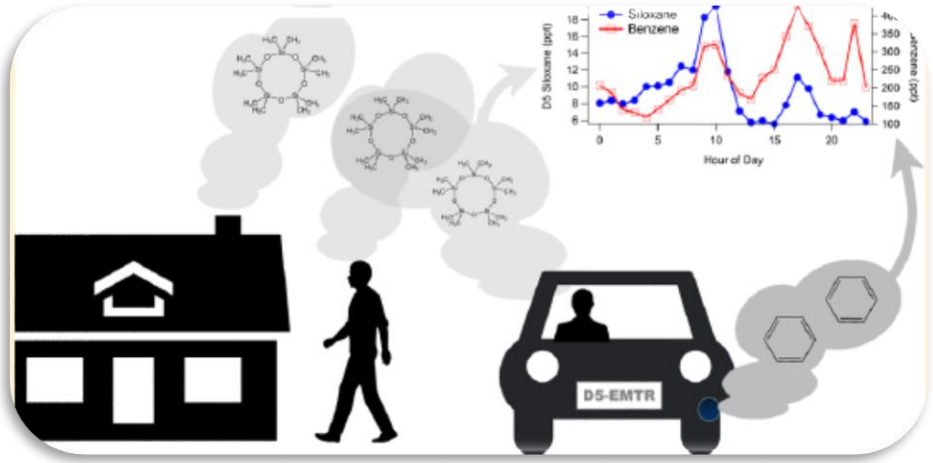
Indoor VOCs

- Carcinogenicity in some of the compounds
- Damage to the liver
- Damage to kidneys and central nervous system
- Eye, nose and throat irritation
- Headaches
- Loss of coordination; nausea; shortness of breath
- Allergic skin reactions; fatigue and dizziness

https://www.canada.ca/en/health-canada/services/publications/healthy-living/indoor-air-reference-levels-chronic-exposure-volatile-organic-compounds.html#3

Effect of indoor air pollution on outdoor air





Environ. Sci. Technol., 2018, 52 (10), pp 5610–5618, DOI: 10.1021/acs.est.8b00506

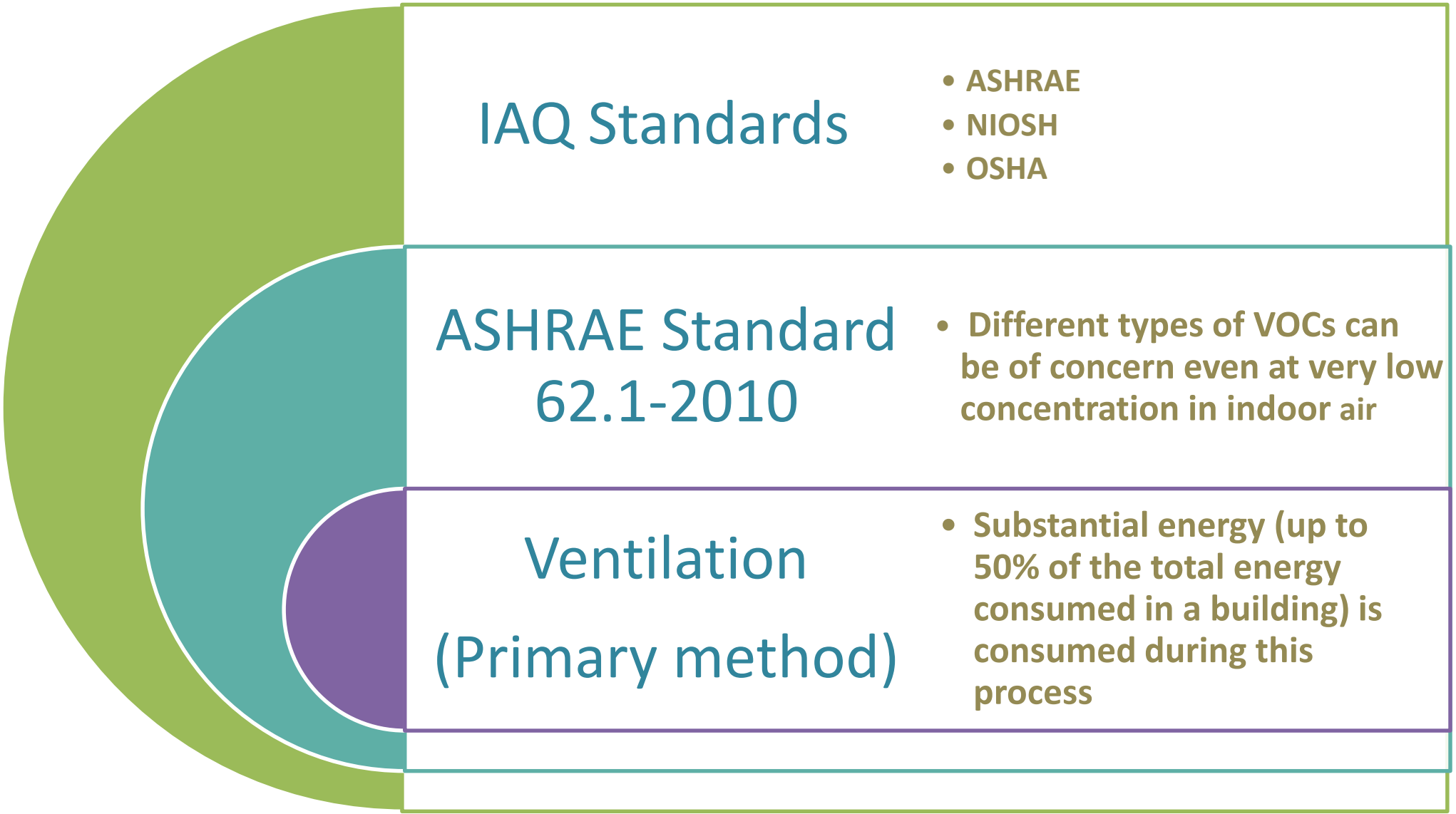
VOCs Removal

The Government of Canada estimates that 14,400 premature deaths per year in Canada can be linked to air pollution.

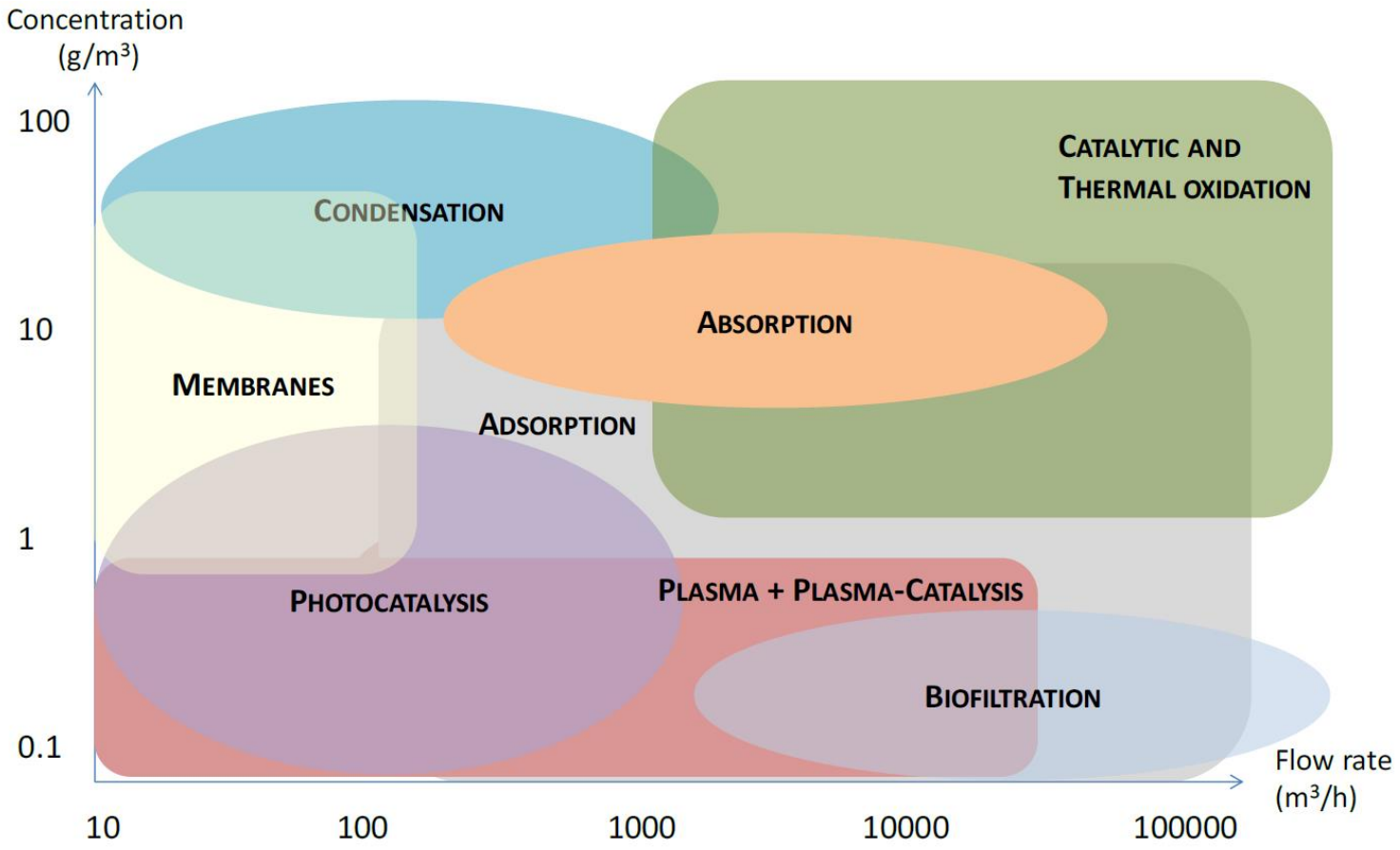
https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/air-quality/toluene-indoor-air-environment-workplace-health.html
http://onlineresize.club/news-club.html

Key impacts of air pollution

Standards


IAQ Standards
• ASHRAE
• NIOSH
• OSHA
ASHRAE Standard 62.1-2010
• Different types of VOCs can be of concern even at very low concentration in indoor air
Ventilation (Primary method)
• Substantial energy (up to 50% of the total energy consumed in a building) is consumed during this process

Current technologies for removal of VOCs



Junliang Wu et al 2017 J. Phys. D: Appl. Phys. 50 475202

Our research

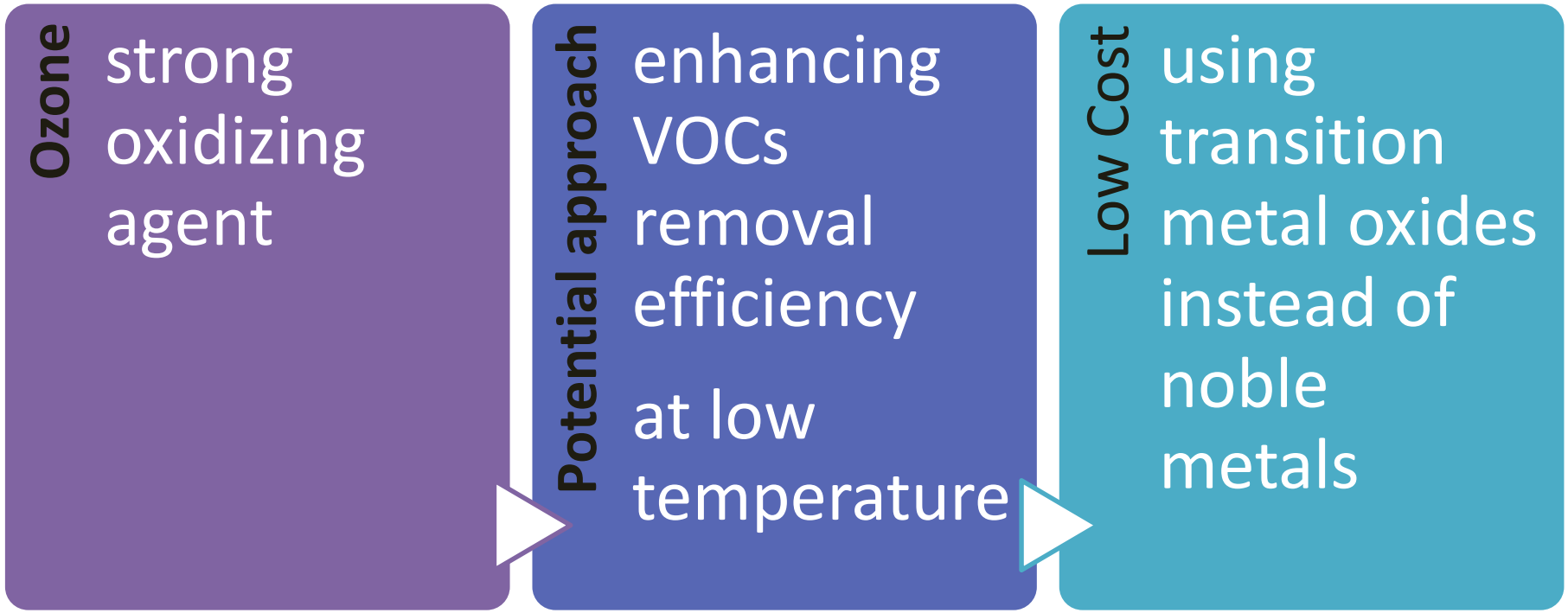
Processes

- Catalytic Ozonation
- Photocatalytic VUV

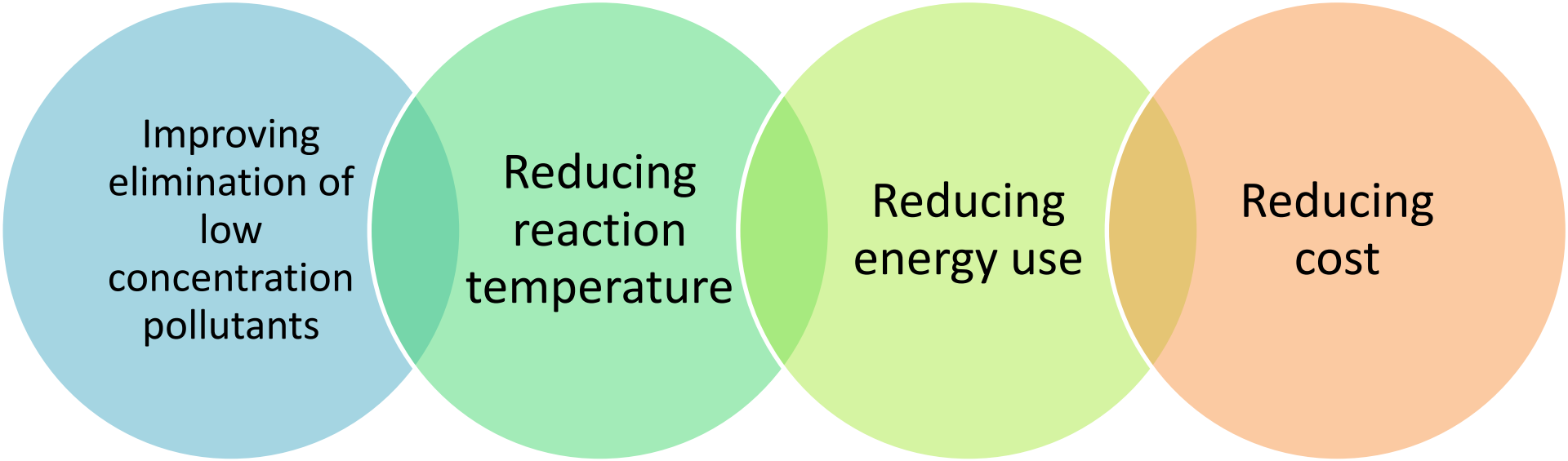
VOCs

- Toluene
- Benzene
- Acetone
- Ammonia
- Mixture of VOCs

Catalytic Ozonation



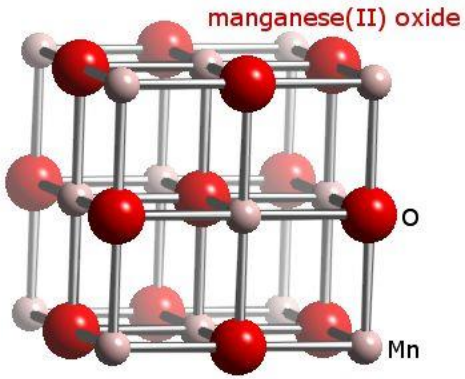
Catalytic Ozonation



Effective catalysts for catalytic ozonation

Transition metal oxides

- Oxides of Mn, Co, Cr, Fe, Cu



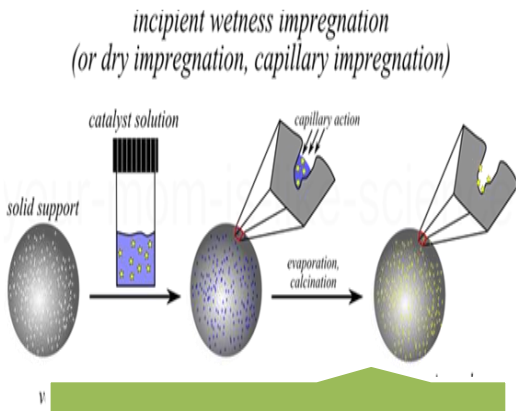
Supports

- Alumina, Zeolite, Silica

Manganese oxides have the highest activity in removal of VOCs from air.

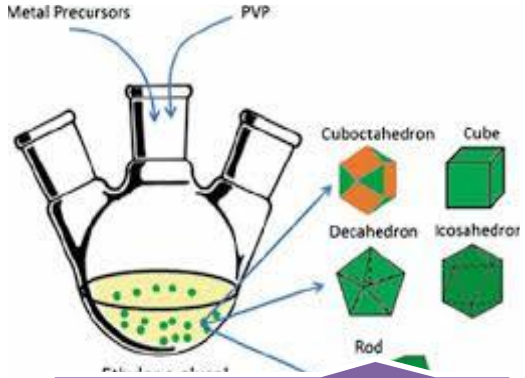
Reed, C., Xi, Y. & Oyama, S.T. (2005). Journal of Catalysis, 235, 378–392.

Catalyst preparation methods



Impregnation

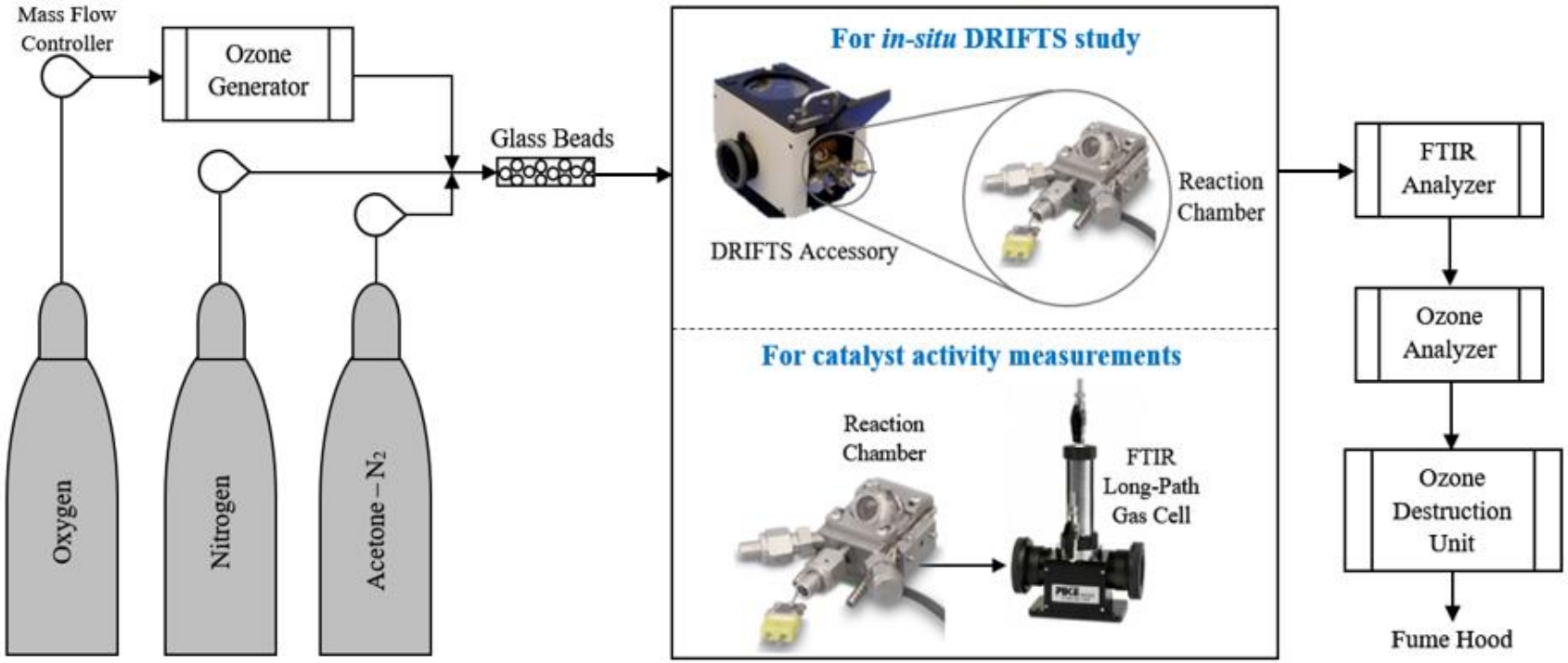
Hydrothermal Method



Polyol Method

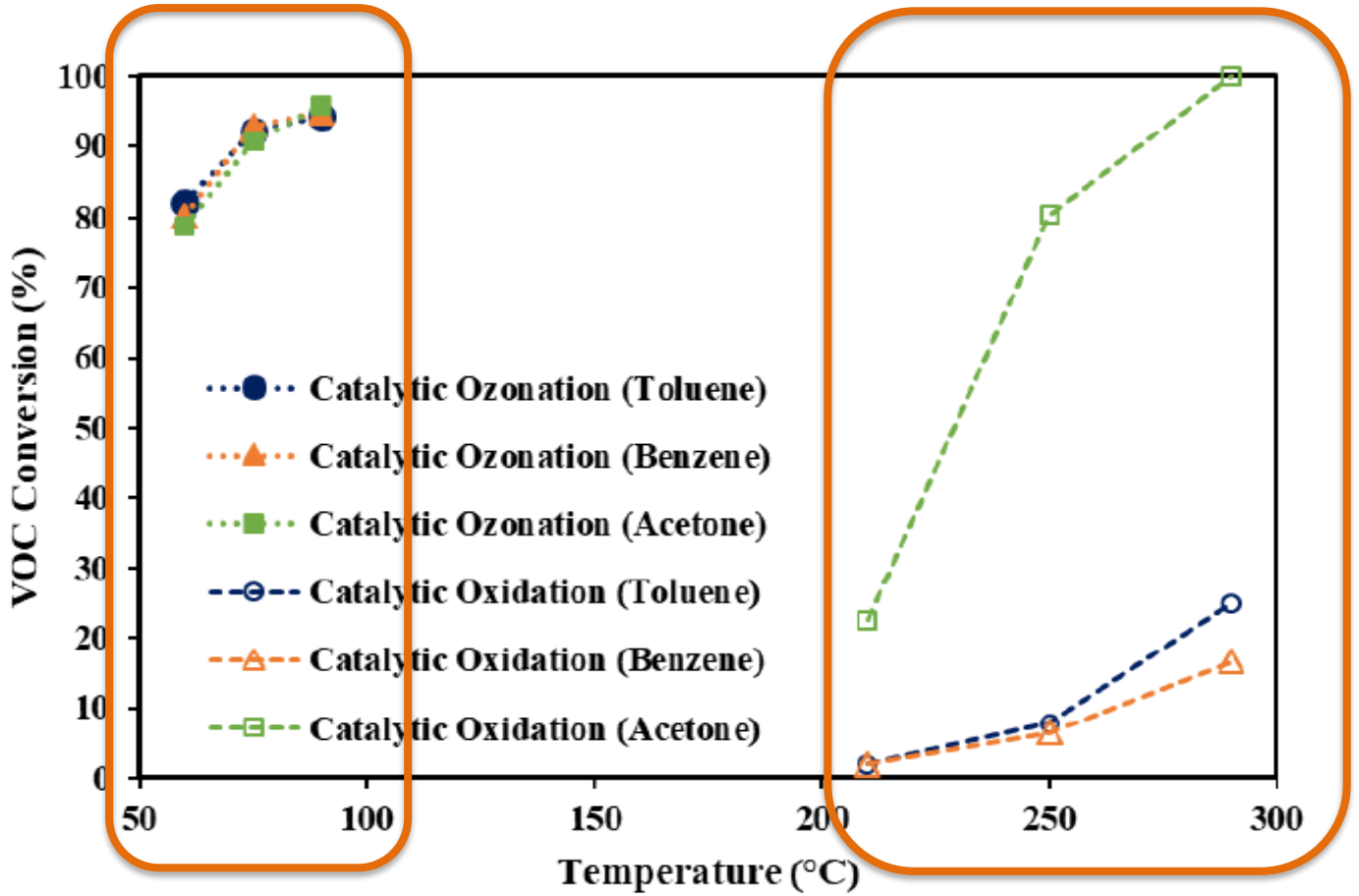
Synthesis of Solid Catalysts, edited by Krijn P. de Jong,2009, John Wiley & Sons.

Experimental setup for catalytic ozonation



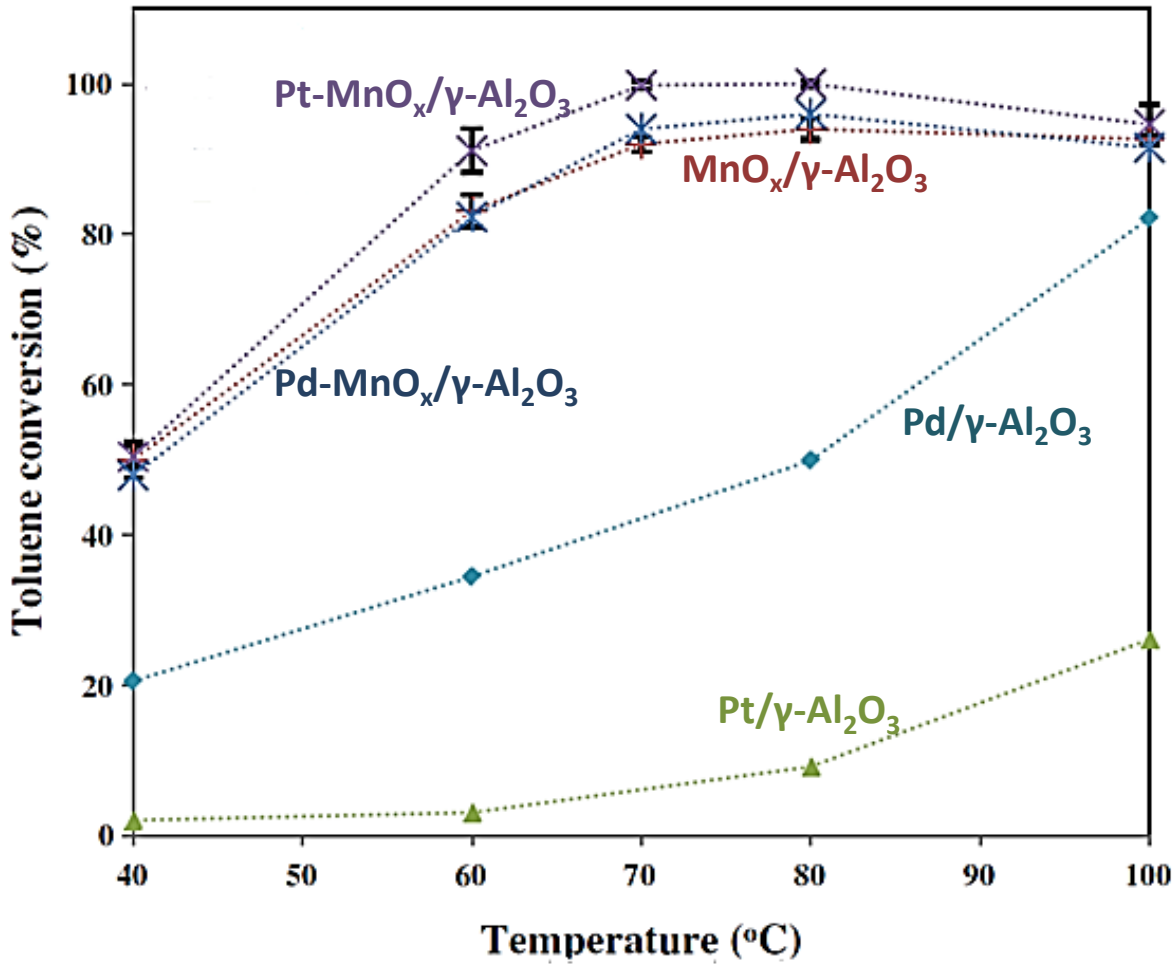
Summary of our findings

Catalytic oxidation vs catalytic ozonation



Single VOC (120 ppmv) streams of toluene, benzene and acetone;
WHSV = 300 L h^{-1} g^{-1}, [O_3] = 1100 ppmv

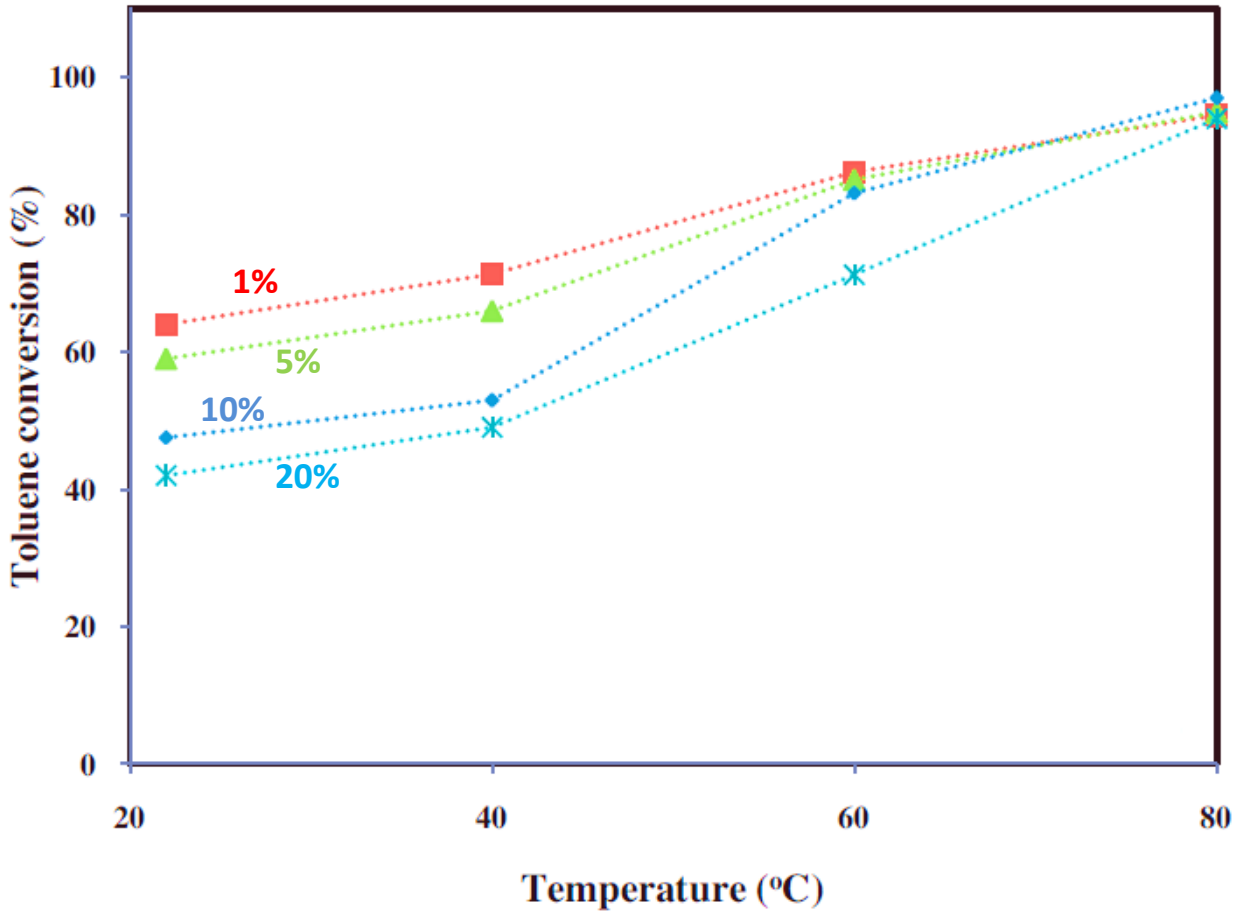
Activity of single and dual metal catalysts



[O_3] = 1050 ppmv,
[Toluene]=120ppmv

Ebrahim Rezaei, Jafar Soltan, Ning Chen, Jinru Lin,Chemical Engineering Journal 214 (2013) 219–228.

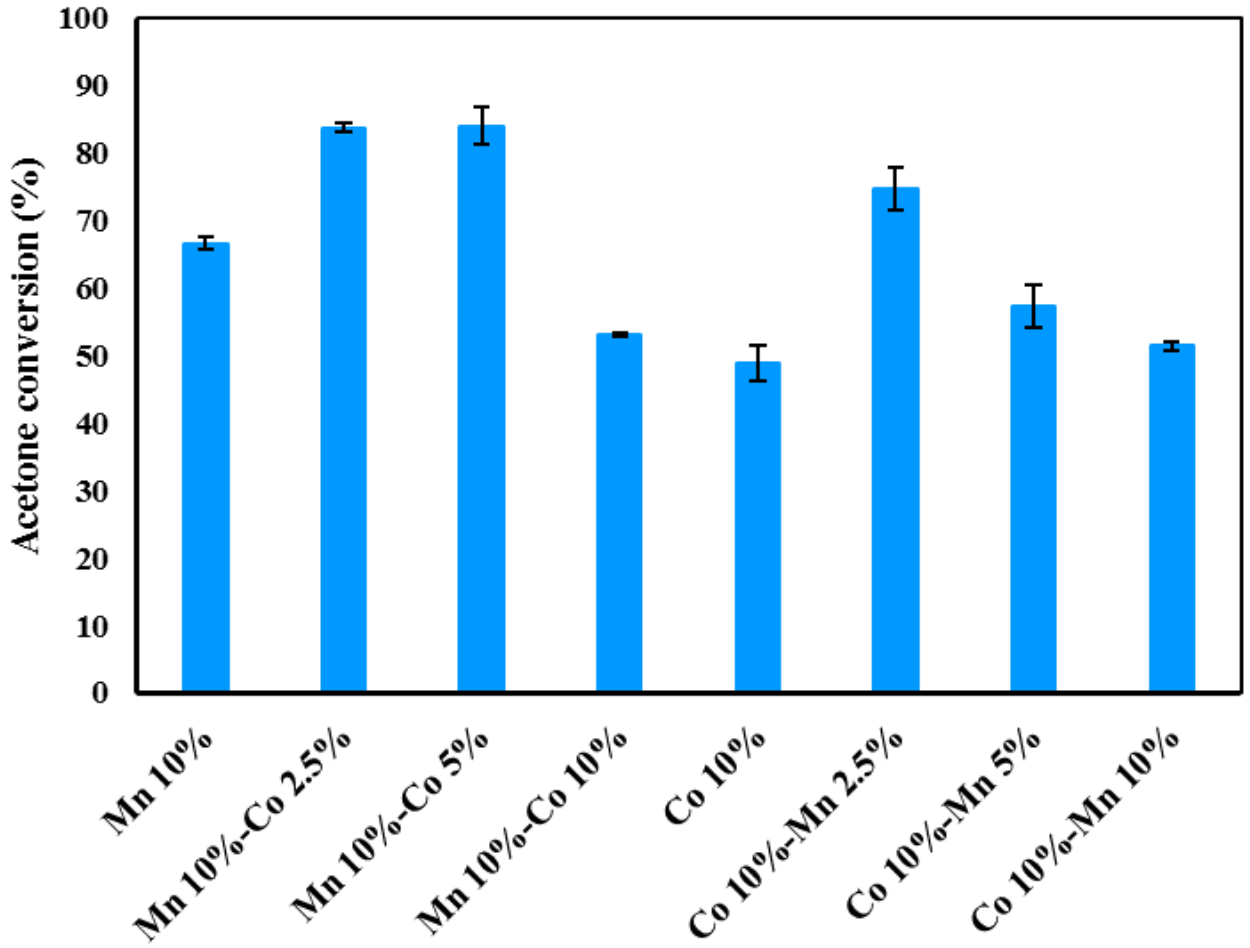
Effect of metal content on catalytic activity



MnO_x/γ-alumina catalyst
$[O_3]$ = 1050 ppmv
[Toluene]=120ppmv

Ebrahim Rezaei, Jafar Soltan, Ning Chen,Applied Catalysis B: Environmental 136– 137 (2013) 239– 247

Effect of promters content in activity of catalyst

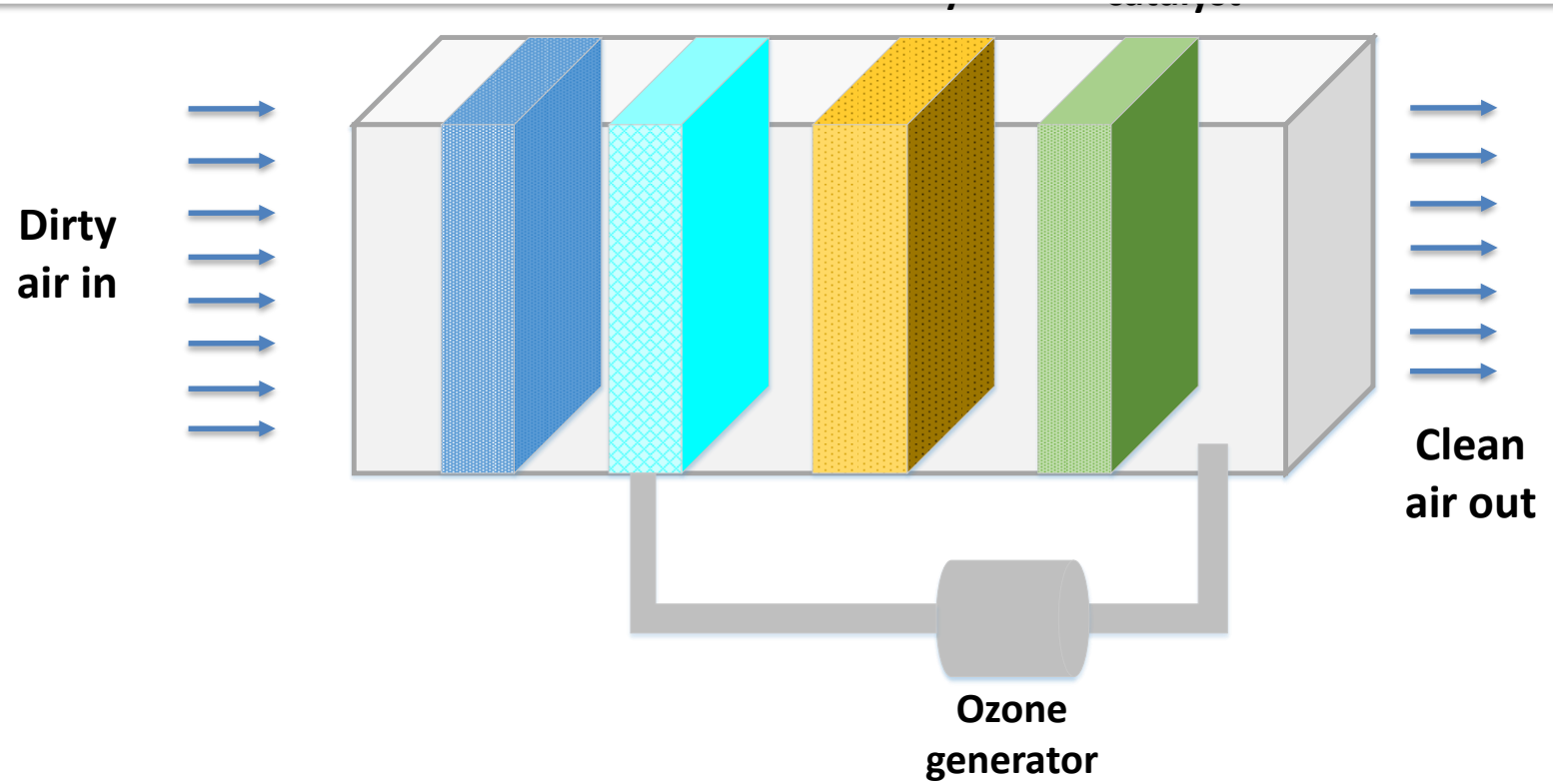


Activity of catalysts at 25 ˚C and 150 min of reaction
$[O_3]$ = 1200 ppmv,
[Acetone]=150ppmv

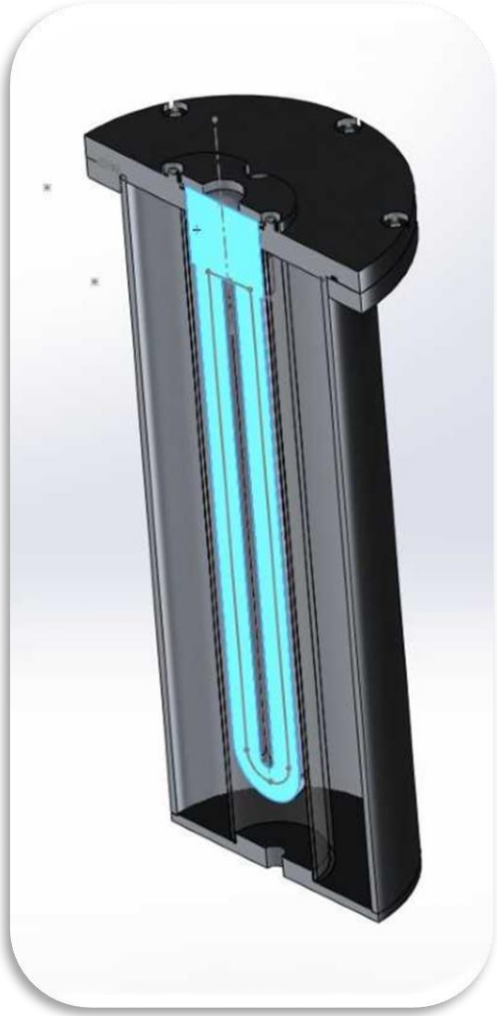
Unpublished

Commercialization

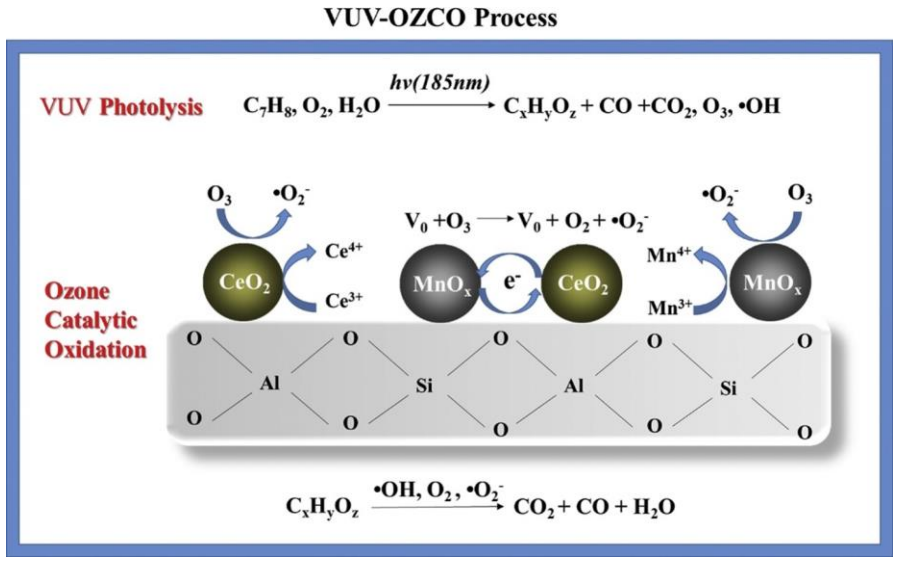
It is estimated that the cost of catalytic oxidation of VOCs using ozone is about 50% less than the conventional oxidation process.



Ongoing research



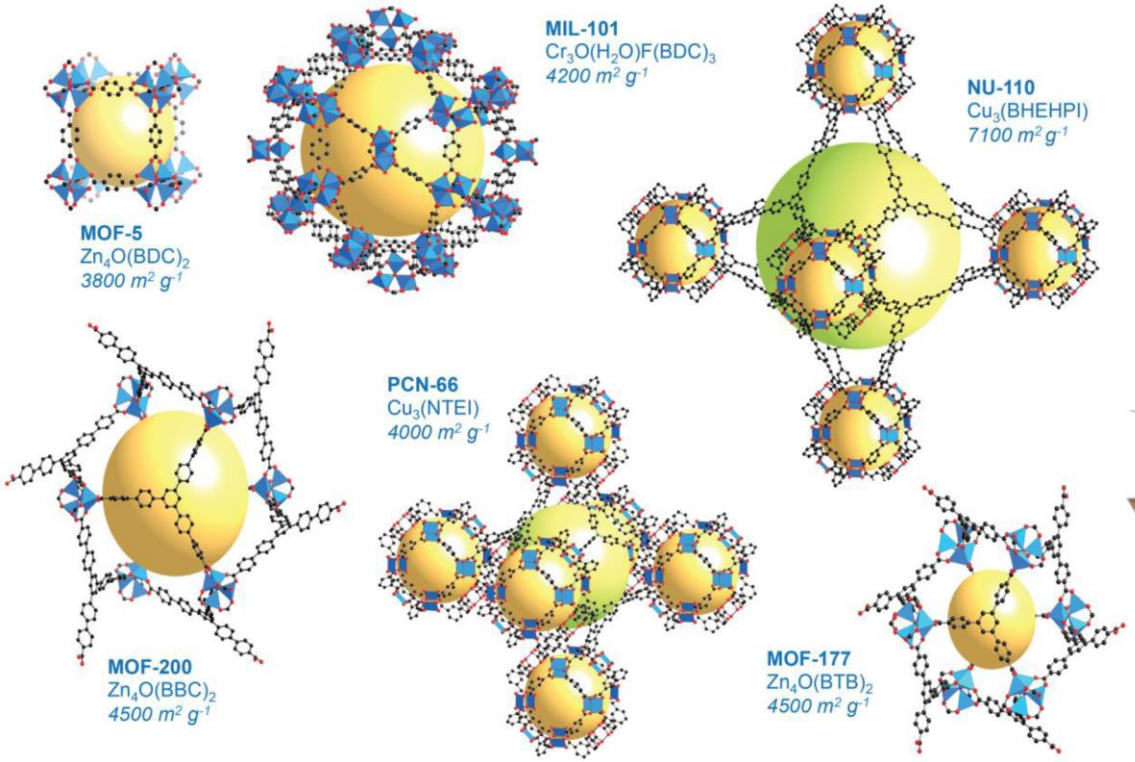
Synergetic degradation of VOCs by Vacuum Ultraviolet Photolysis and Catalytic Ozonation

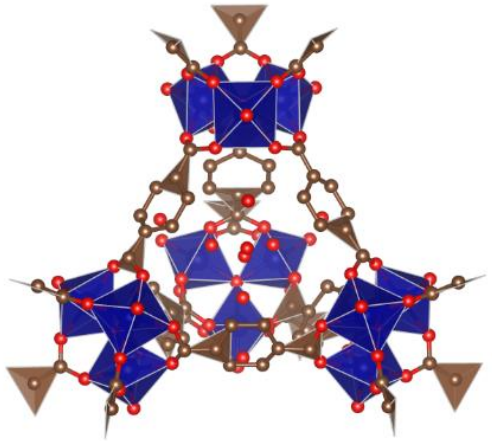


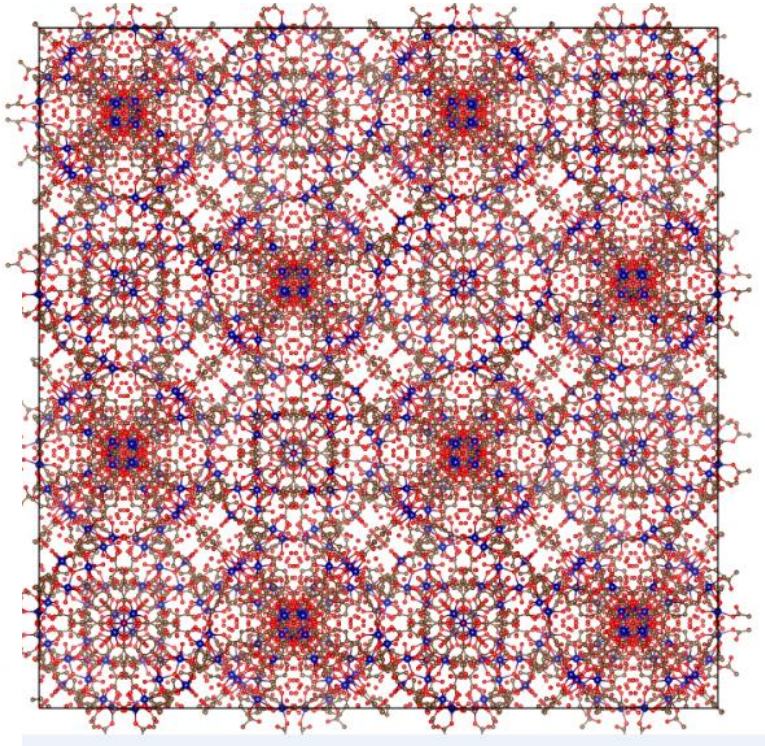
Yajie Shu, Miao He, Jian Ji, Haibao Huang, Shengwei Liu, Dennis Y.C. Leung, Journal of Hazardous Materials, 364(2019)770-779.

Ongoing Research

Metal Organic Frameworks (MOFs)







https://www.intechopen.com/books/semiconductor-photocatalysis-materials-mechanisms-and-applications/metal-organic-frameworks-as-emerging-photocatalysts

Concluding remarks

- Catalytic processes based on controlled reactions, with ozone gas, are effective methods to oxidize VOCs under controlled conditions with minimum consumption of energy.
- Removal of indoor air VOCs lead to reduced make up air, more energy saving.
- Efficiency of this process are demonstrated for most common VOCs including toluene, benzene, and acetone.

Acknowledgements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RESEARCH COUNCIL

Thank you!


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More References

- Matthew M. Coggon, Brian C. McDonald, Alexander Vlasenko, Patrick R. Veres, François Bernard, Abigail R. Koss, Bin Yuan, Jessica B. Gilman, Jeff Peischl, Kenneth C. Aikin, Justin DuRant, Carsten Warneke, Shao-Meng Li, and Joost A. de Gouw, Environ. Sci. Technol. 2018, 52, 5610−5618.
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- E. Rezaei, J. Soltan, N. Chen, Appl. Catal. B Environ. 136–137 (2013) 239–247. doi:http://dx.doi.org/10.1016/j.apcatb.2013.01.061.