

Electronic Cigarette: The Knowns, Known Unknowns, and Unknown Unknowns

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A 7th person has died from vaping-related causes. The CDC is stepping up its probe of e-cigarette illnesses
(CNN) A California man has become the seventh person to die from a vaping-related illness in the United States as the nation's leading health ...

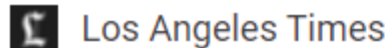
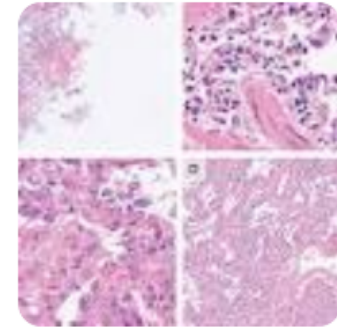
3 weeks ago



Lung Damage From Vaping Resembles Chemical Burns, Report Says

The lung damage in some people who have become ill after vaping nicotine or marijuana products resembles a chemical burn, doctors from ...

6 days ago



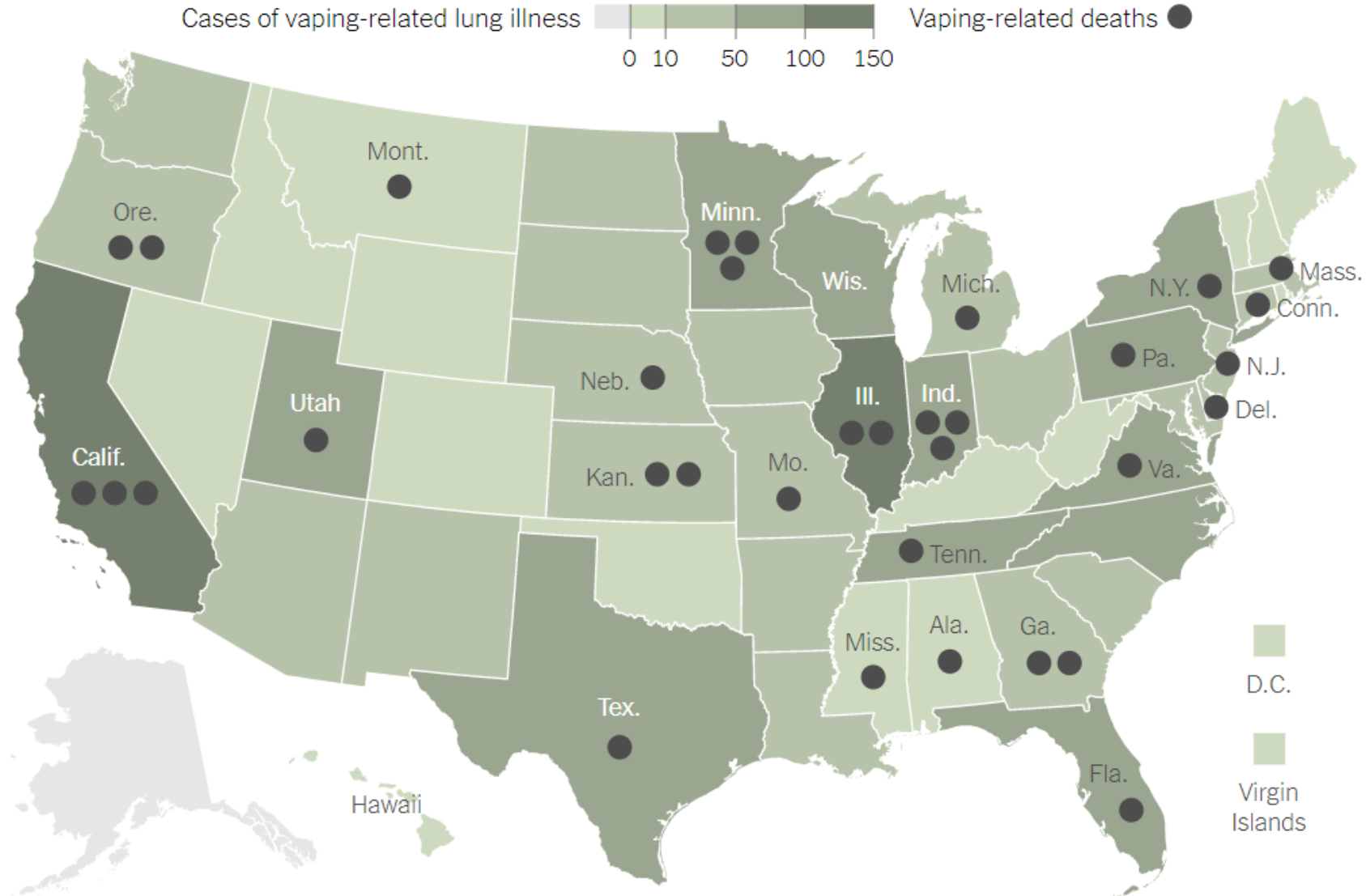
The recent vaping deaths are bad. The long term toll will be ...

The Centers for Disease Control and Prevention has linked vaping to 1,479 cases of ... At least 33 people have died since the outbreak began.

4 days ago



The CDC and state agencies have reported 1,604 lung injury cases and 34 deaths linked to vaping



What are E-cigs?

- Battery-powered nicotine delivery systems
- Unlike tobacco cigarette, e-cig emissions are generated by the **vaporization of e-liquid**

E-liquid Main Ingredients:

Propylene Glycol (PG)
Vegetable Glycerin (VG)
Nicotine
Flavorings



Heating Coil

1st Generation



2nd Generation



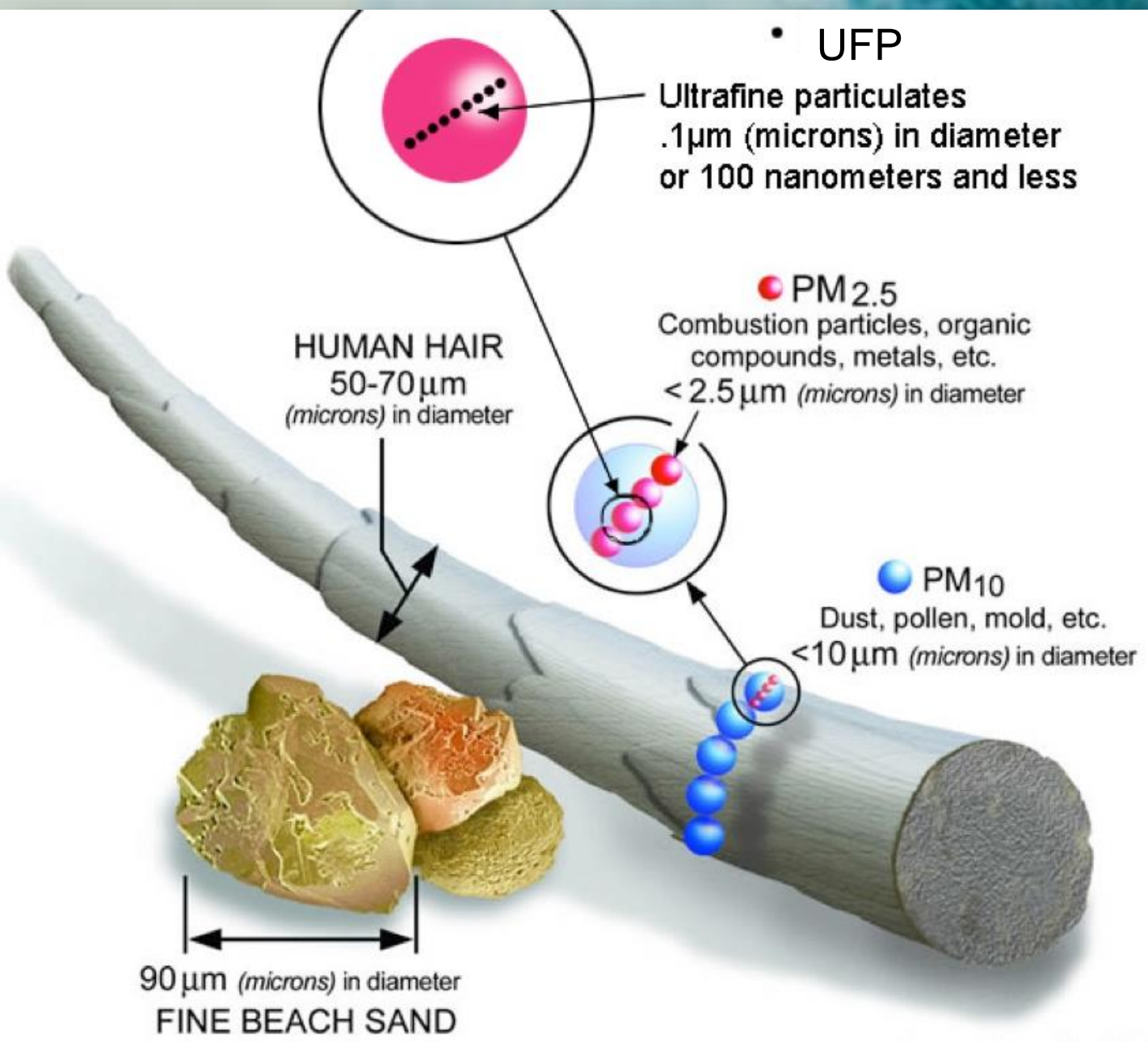
3rd Generation



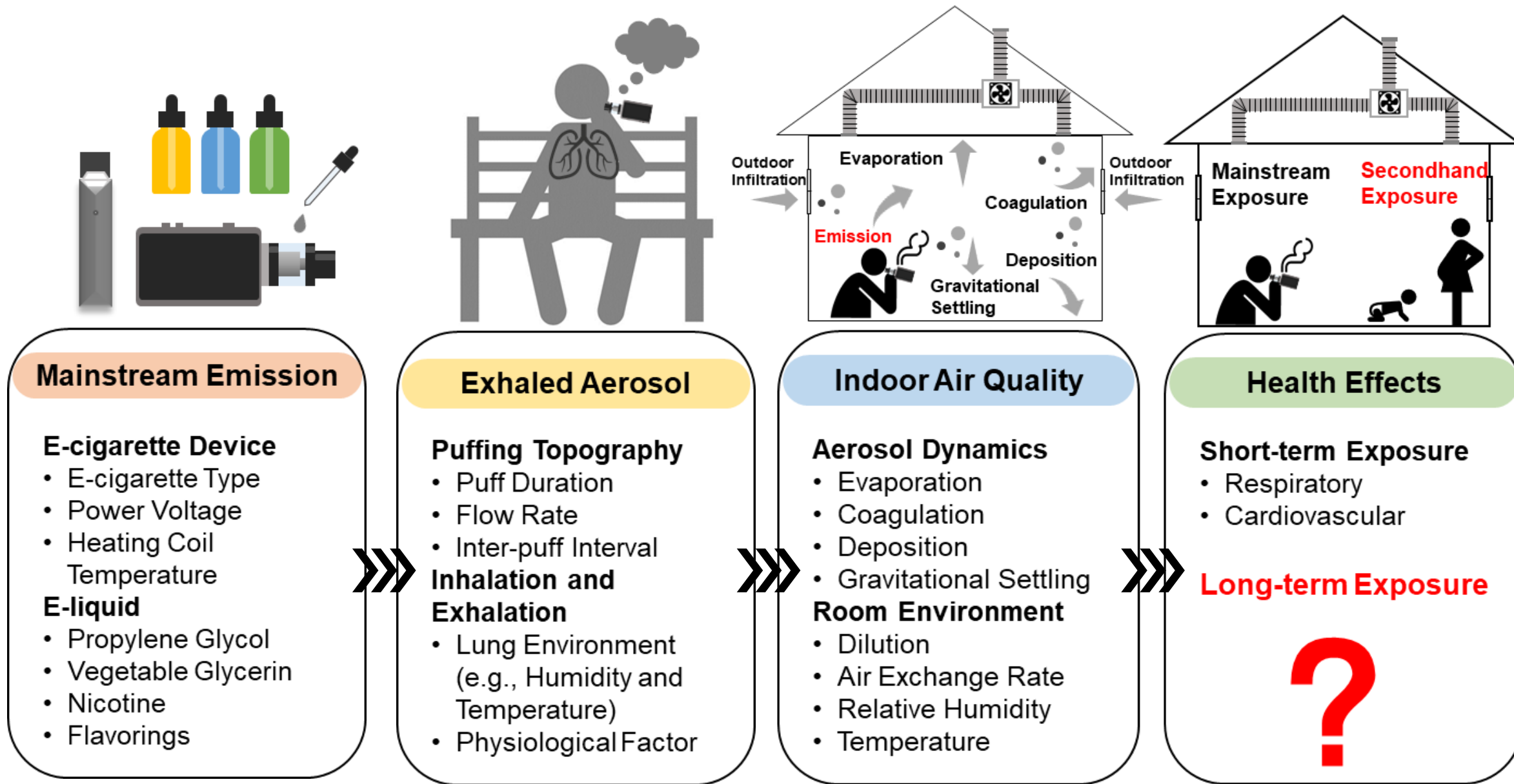
4th Generation



What comes out of E-cigs?



From E-cig emissions, to secondhand exposures, to potential health effects



From E-cig emissions, to secondhand exposures, to potential health effects



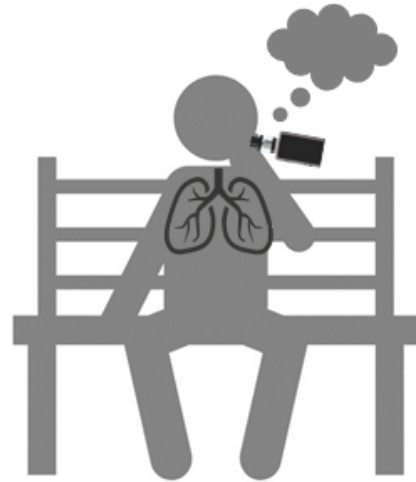
Mainstream Emission

E-cigarette Device

- E-cigarette Type
- Power Voltage
- Heating Coil Temperature

E-liquid

- Propylene Glycol
- Vegetable Glycerin
- Nicotine
- Flavorings



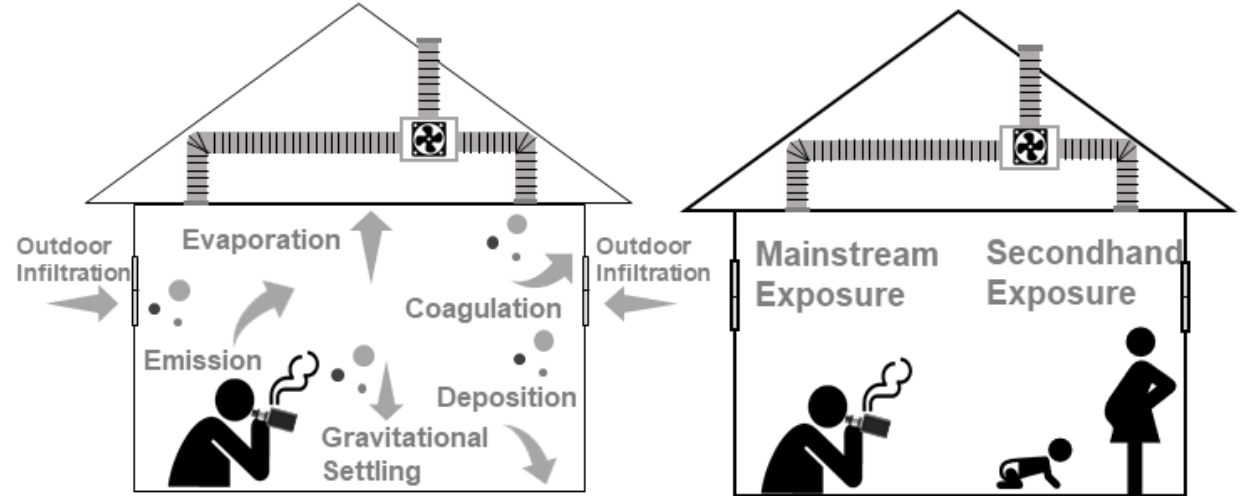
Exhaled Aerosol

Puffing Topography

- Puff Duration
- Flow Rate
- Inter-puff Interval

Inhalation and Exhalation

- Lung Environment (e.g., Humidity and Temperature)
- Physiological Factor



Indoor Air Quality

Aerosol Dynamics

- Evaporation
- Coagulation
- Deposition
- Gravitational Settling

Room Environment

- Dilution
- Air Exchange Rate
- Relative Humidity
- Temperature

Health Effects

Short-term Exposure

- Respiratory
- Cardiovascular

Long-term Exposure

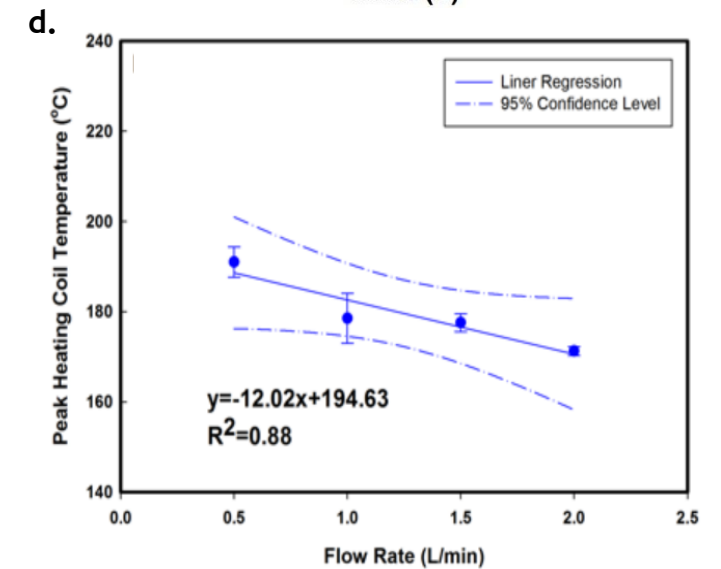
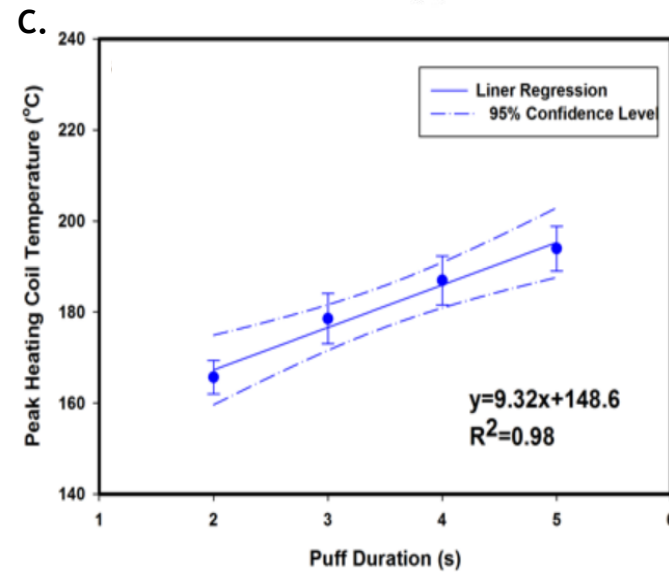
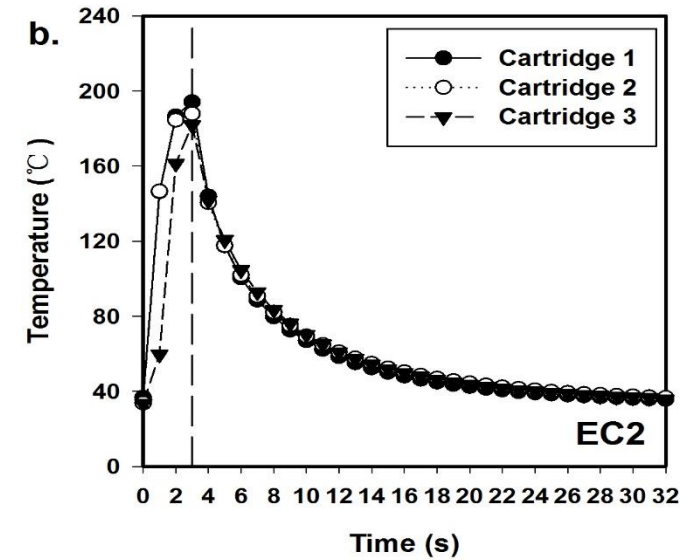
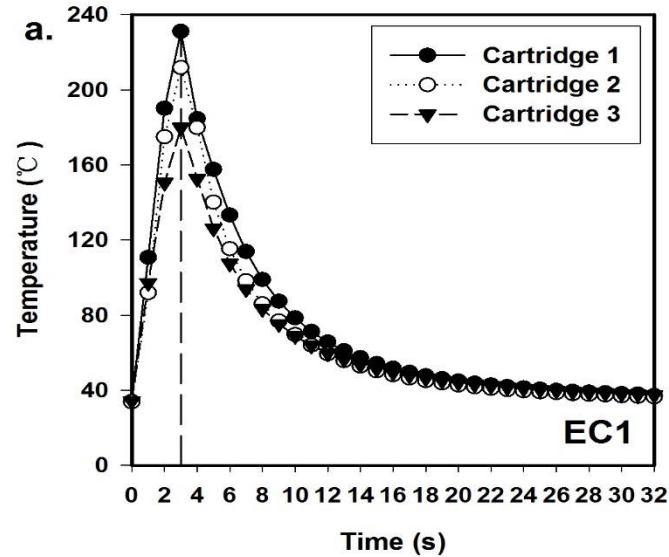


E-cig Devices

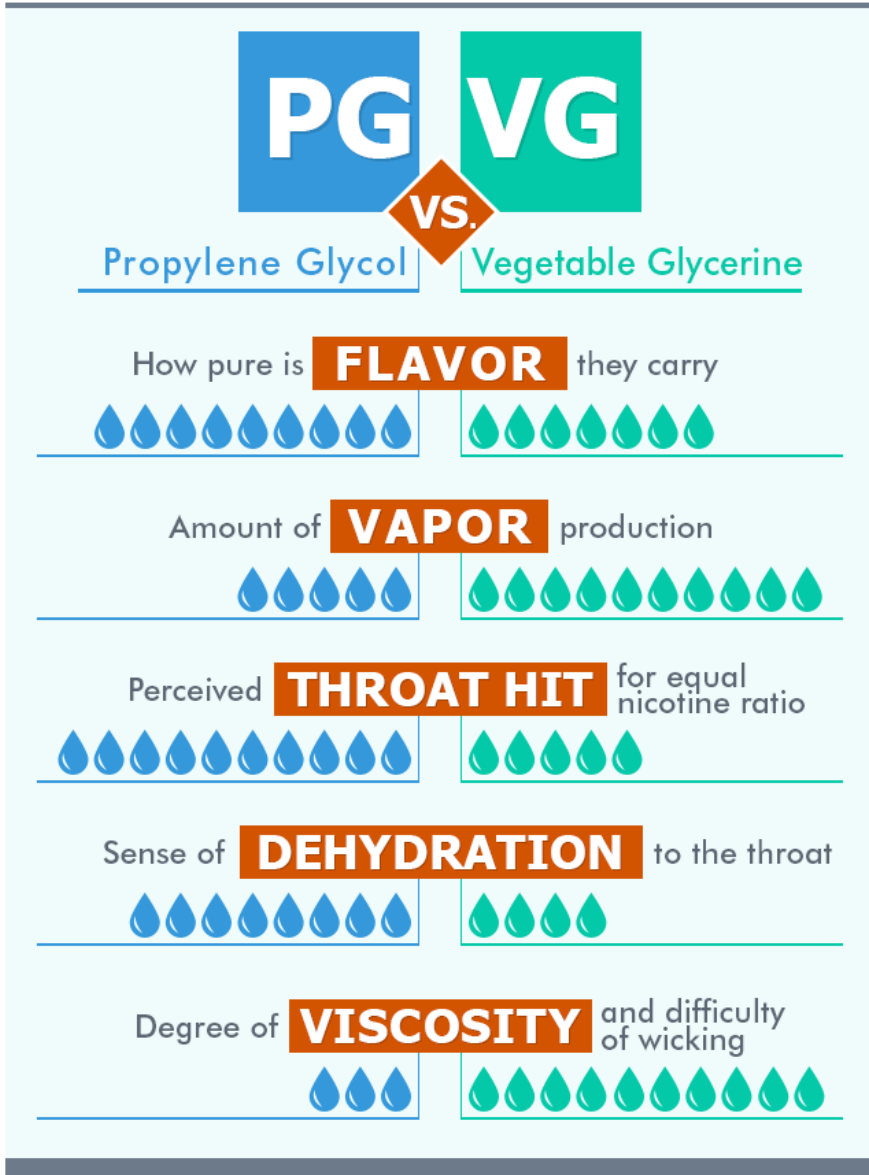


E-cig Devices

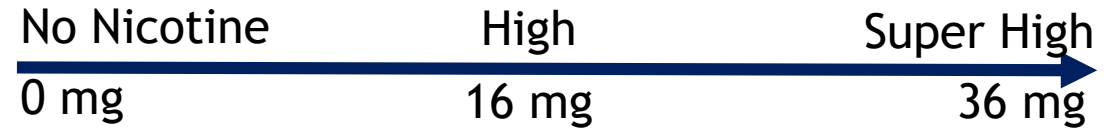
- Peak temperature of heating coil ranged from 160 °C to 240 °C.
- Heating coil temperature increases with a longer puff duration and lower puff flow rate



E-liquids



Nicotine

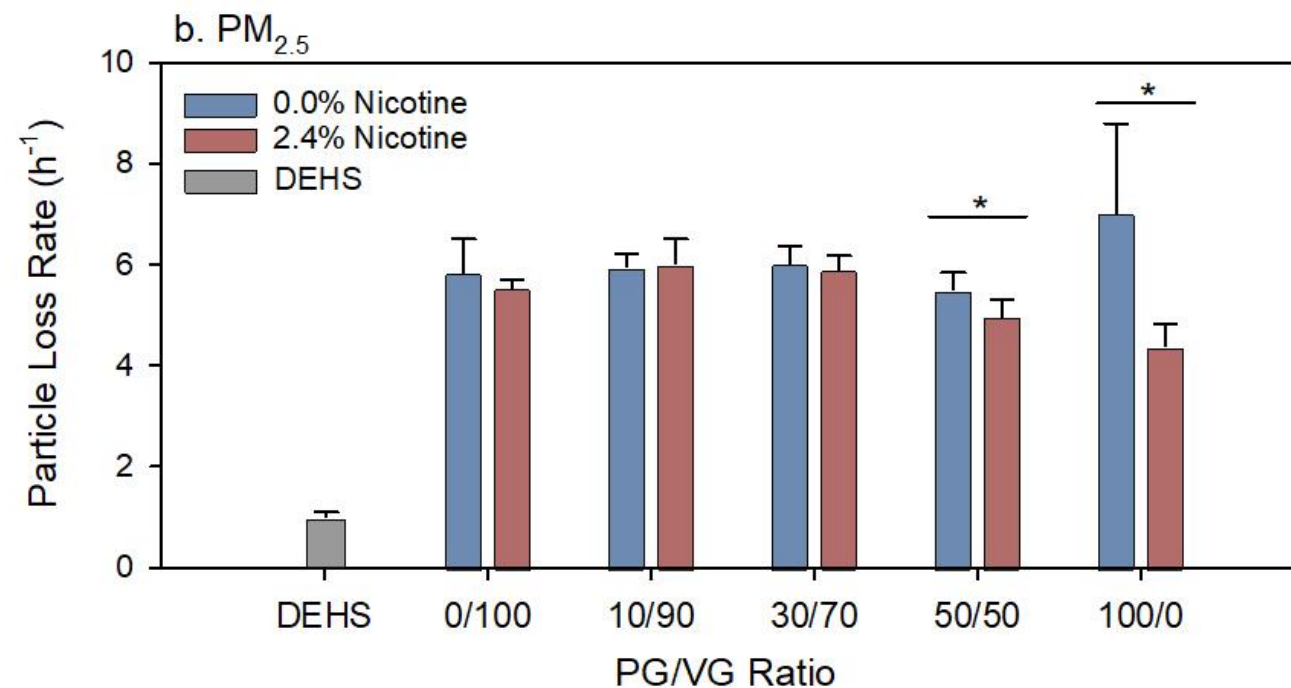
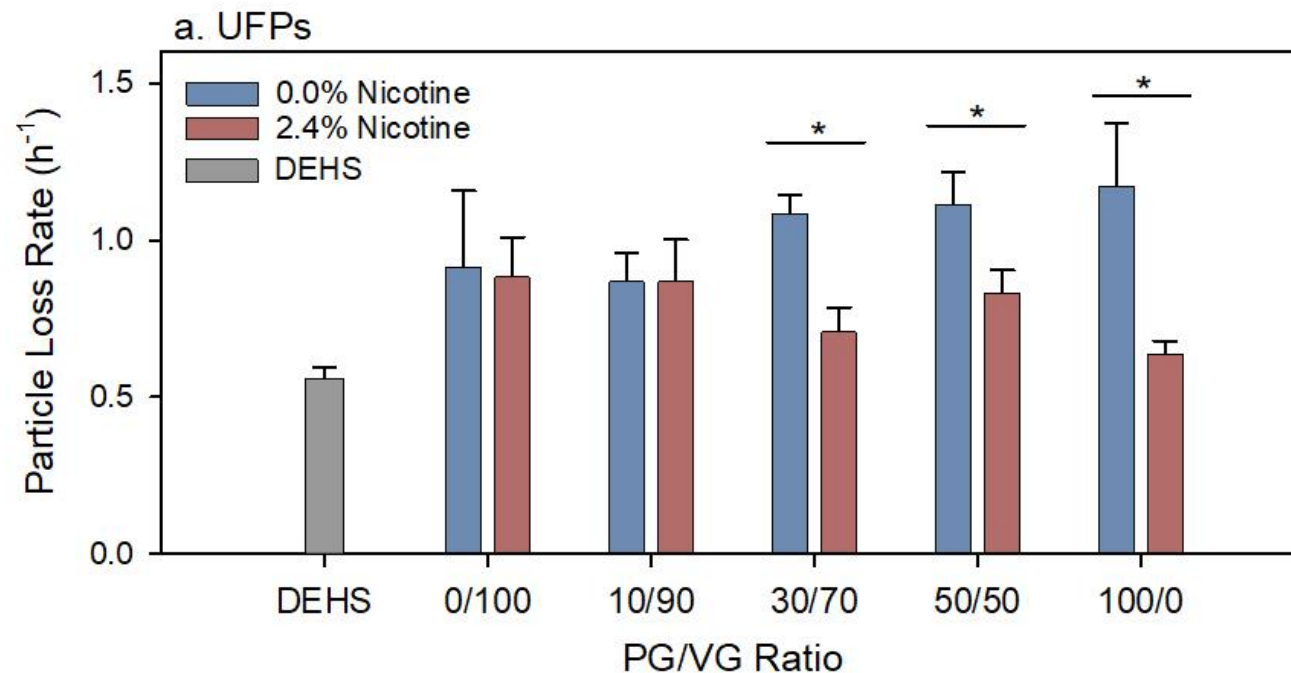


Flavorings

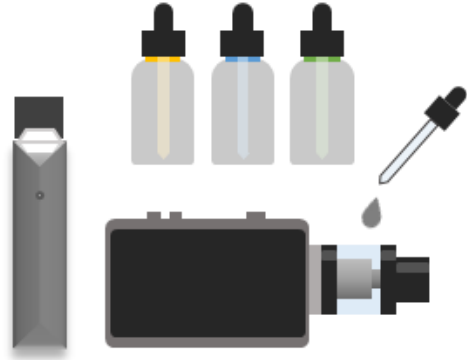


E-liquids

- **Particle loss rate varies at different PG/VG ratios and nicotine levels**
- **E-cig aerosol particles are more volatile than nonvolatile diethyl-hexyl sebacate (DEHS)**



From E-cig emissions, to secondhand exposures, to potential health effects



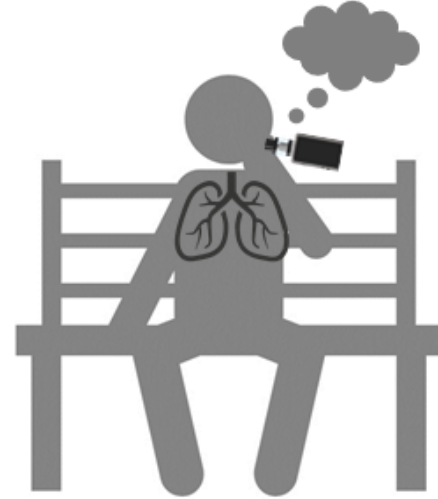
Mainstream Emission

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E-liquid

- Propylene Glycol
- Vegetable Glycerin
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- Flavorings



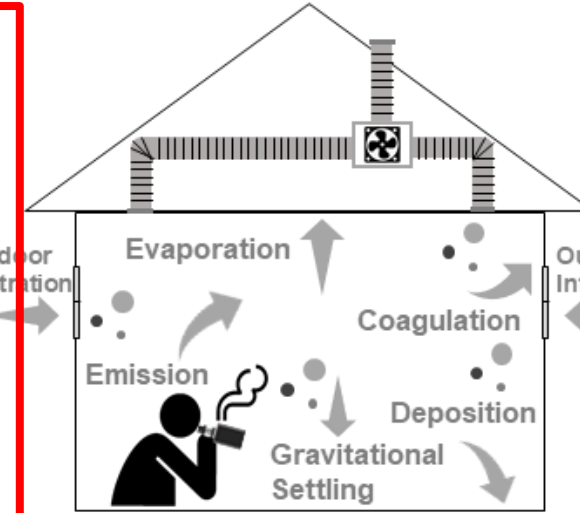
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Puffing Topography

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Inhalation and Exhalation

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Indoor Air Quality

Aerosol Dynamics

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- Coagulation
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Room Environment

- Dilution
- Air Exchange Rate
- Relative Humidity
- Temperature



Health Effects

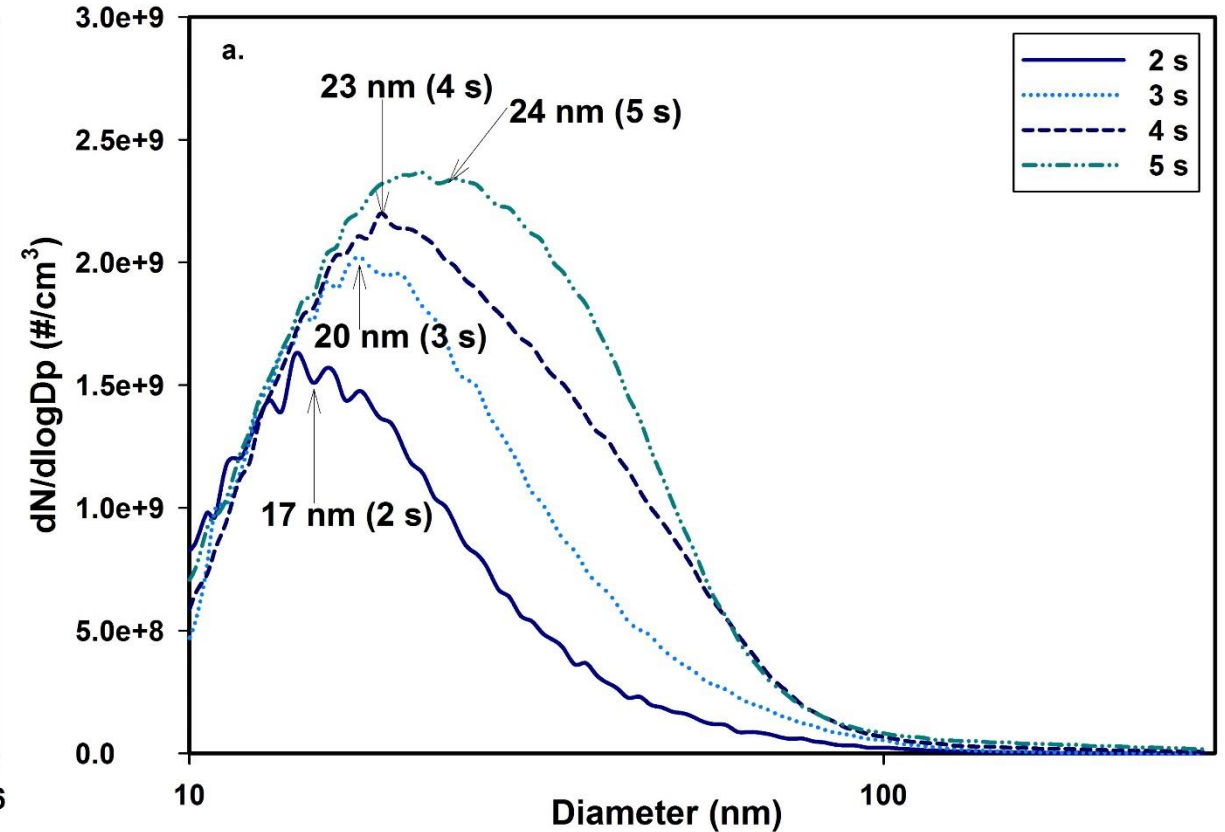
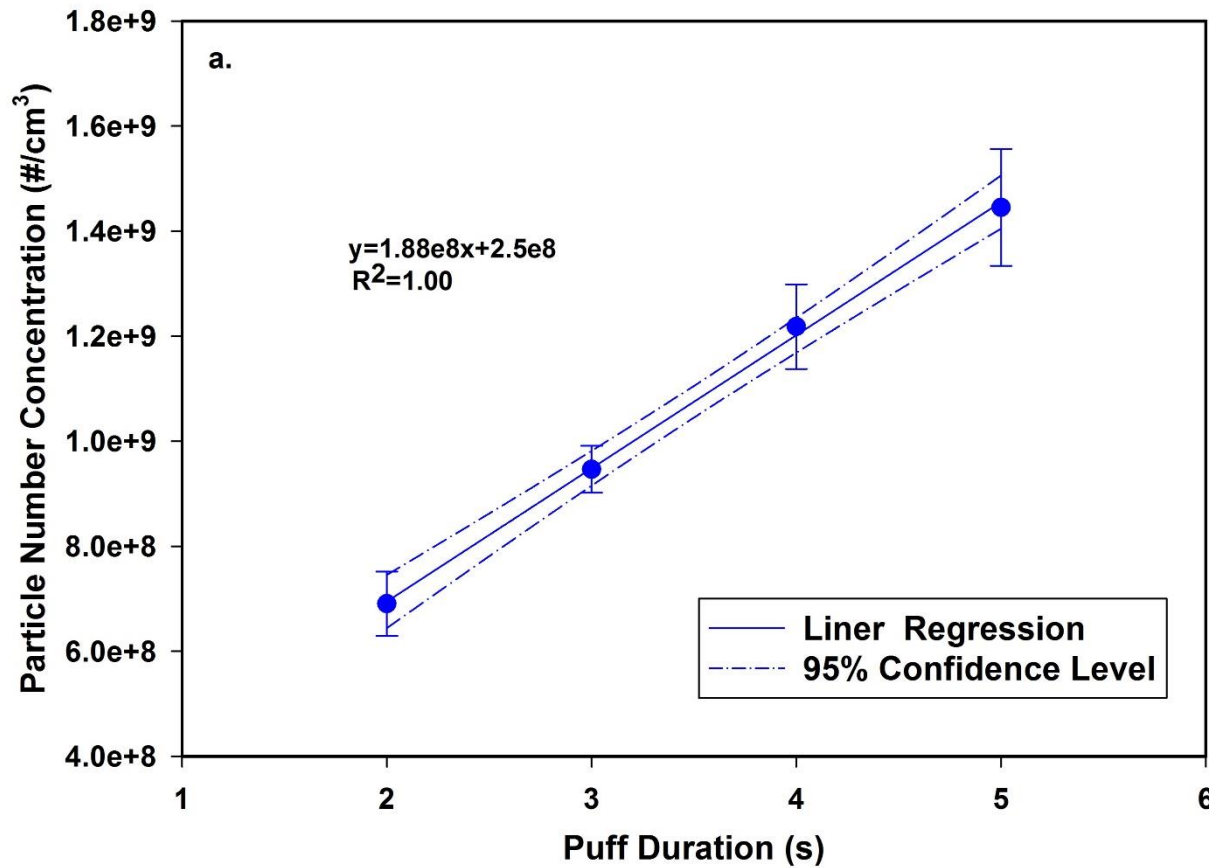
Short-term Exposure

- Respiratory
- Cardiovascular

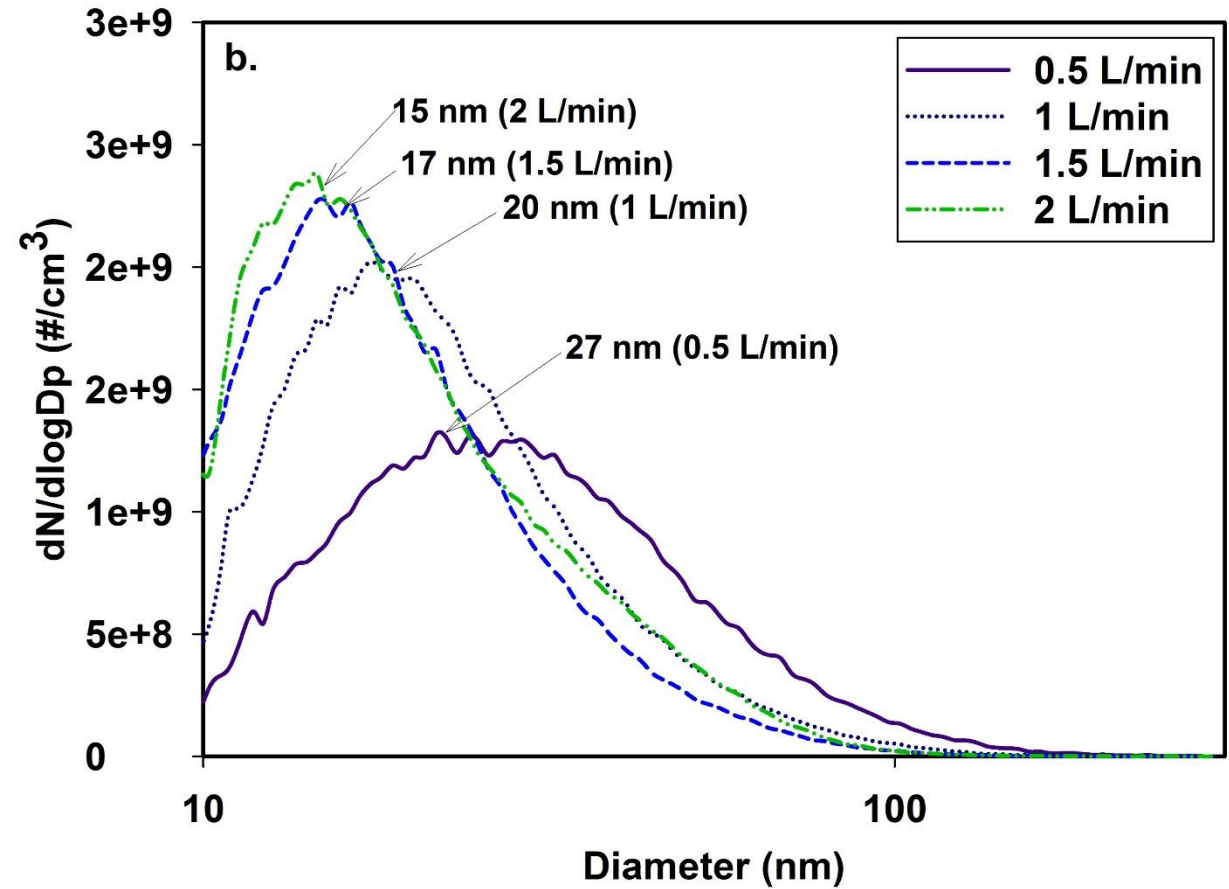
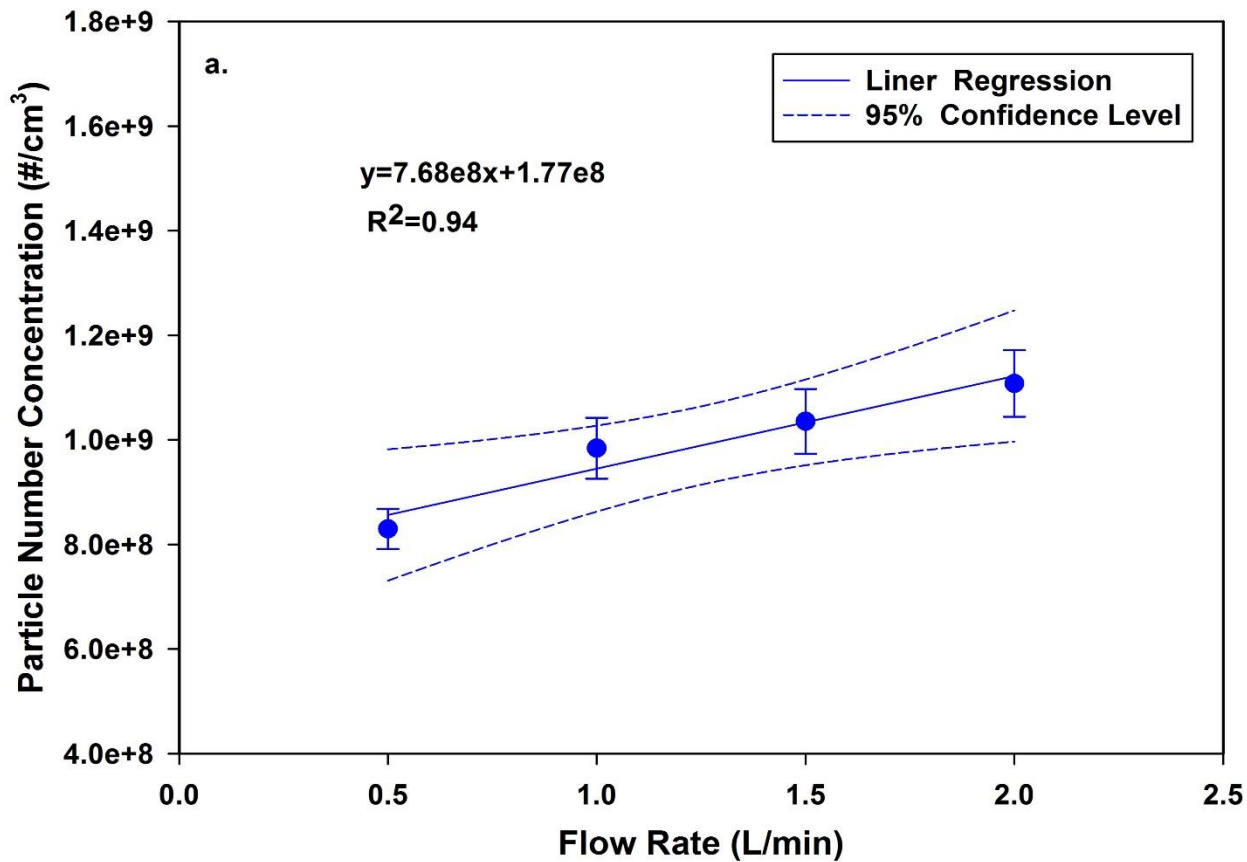
Long-term Exposure



Effects of puff duration on the mainstream e-cig particles

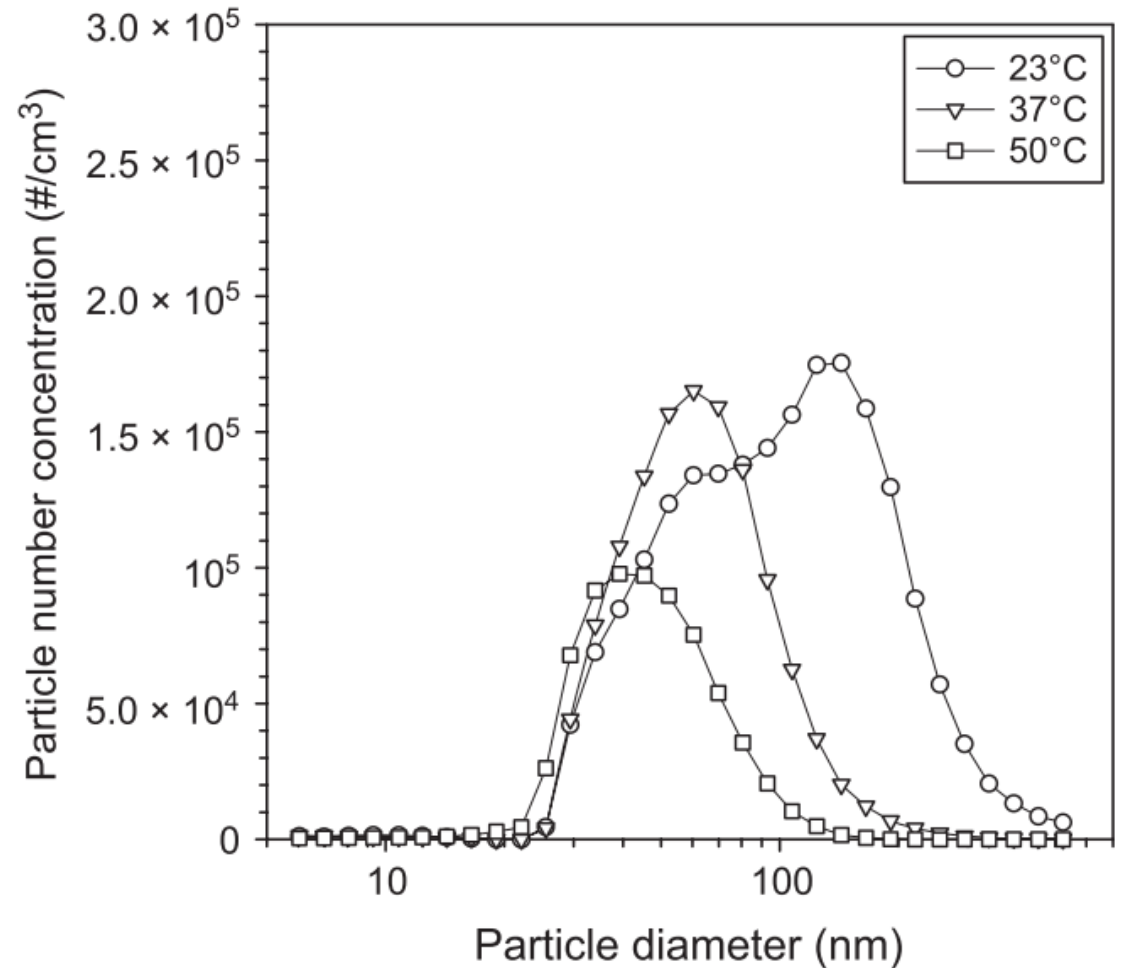


Effects of puff flow rate on the mainstream e-cig particles

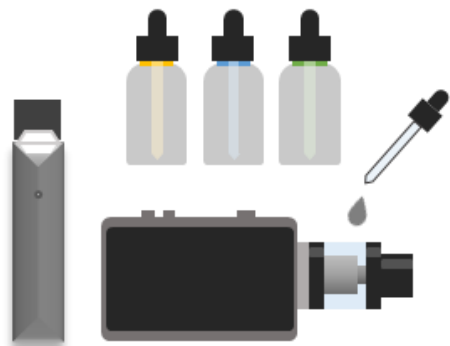


Effects of the Lungs - Humidity & Temperature

- E-cig particles tend to grow in human lungs under high humidity due to the hygroscopic effect (Pichelstorfer et al. 2016; Sosnowski et al. 2016)
- Increasing temperature or decreasing relative humidity may enhance evaporation and reduce particle size (Wright et al. 2016, Schripp et al. 2013)
- Other physiological factors in the respiratory system might also affect e-cig aerosol dynamics



From E-cig emissions, to secondhand exposures, to potential health effects



Mainstream Emission

E-cigarette Device

- E-cigarette Type
- Power Voltage
- Heating Coil Temperature

E-liquid

- Propylene Glycol
- Vegetable Glycerin
- Nicotine
- Flavorings



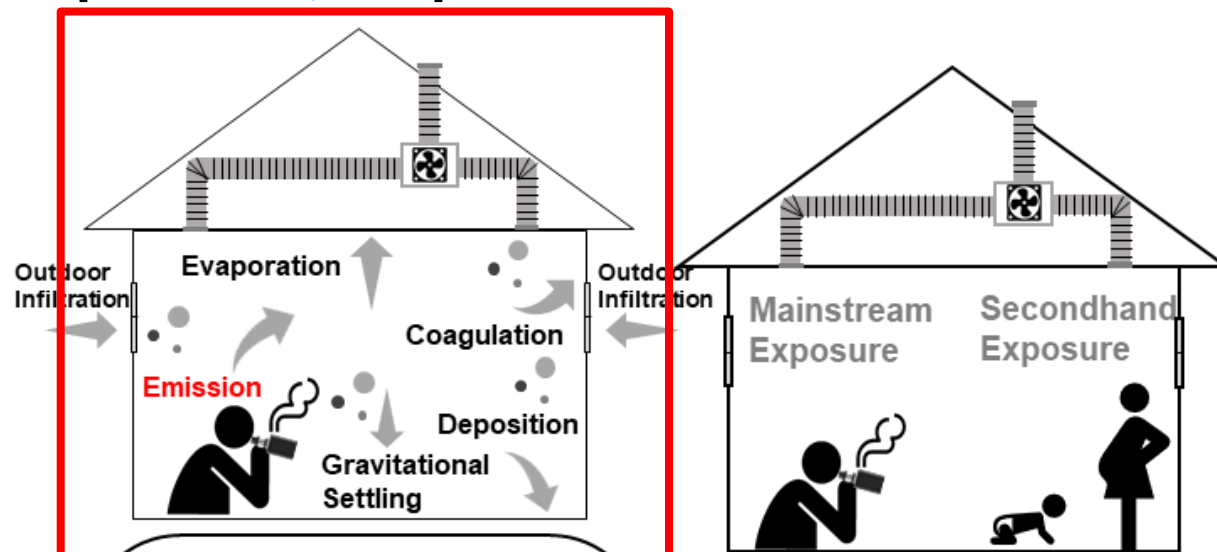
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Puffing Topography

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Indoor Air Quality

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- Coagulation
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- Gravitational Settling

Room Environment

- Dilution
- Air Exchange Rate
- Relative Humidity
- Temperature

Health Effects

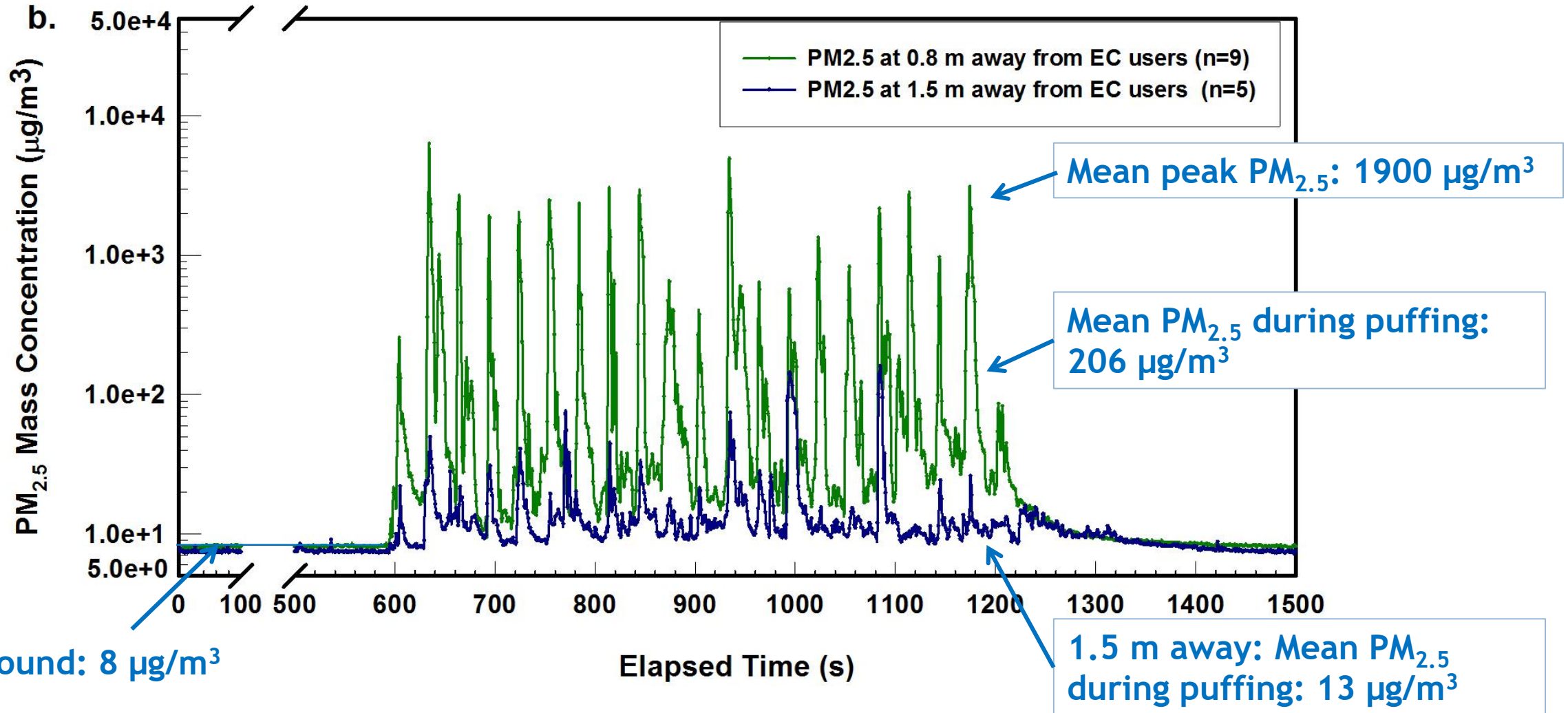
Short-term Exposure

- Respiratory
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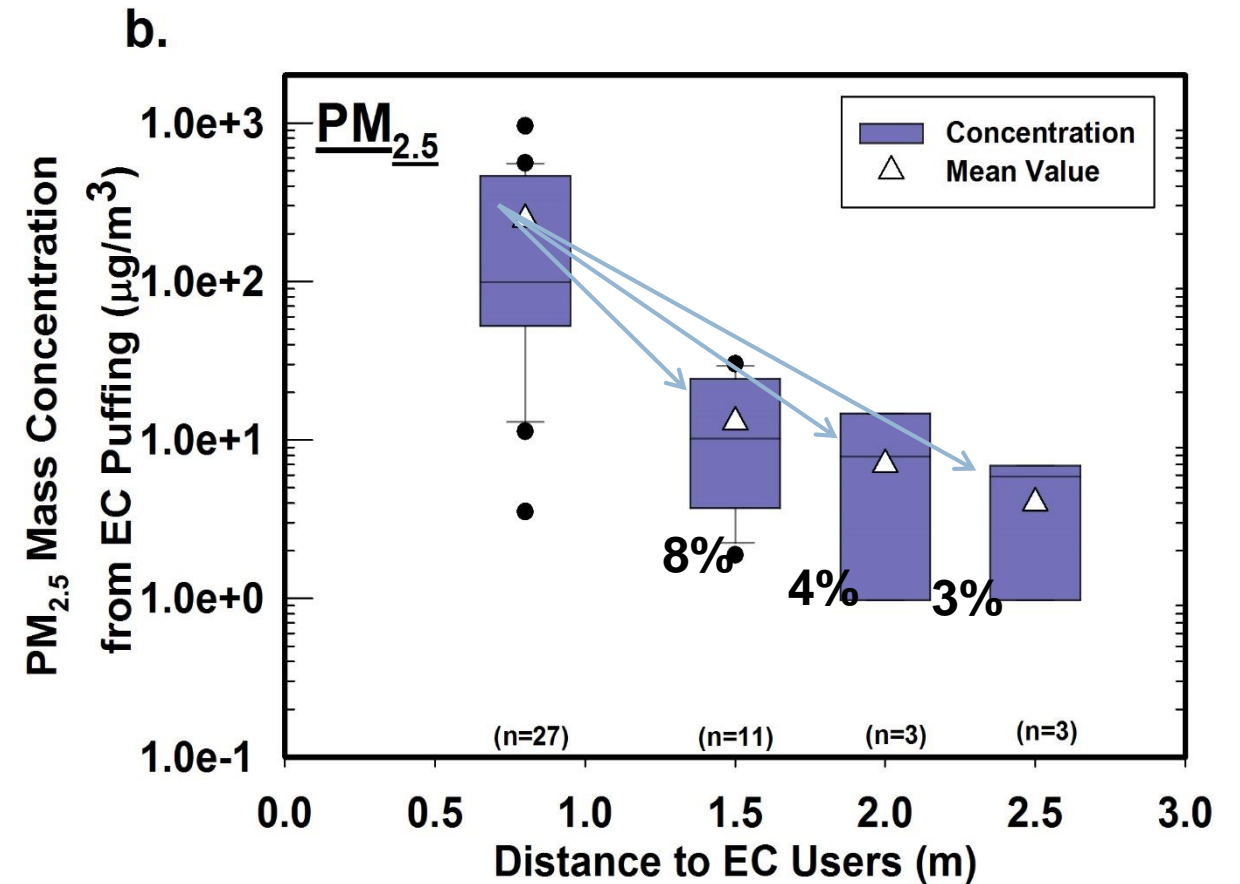
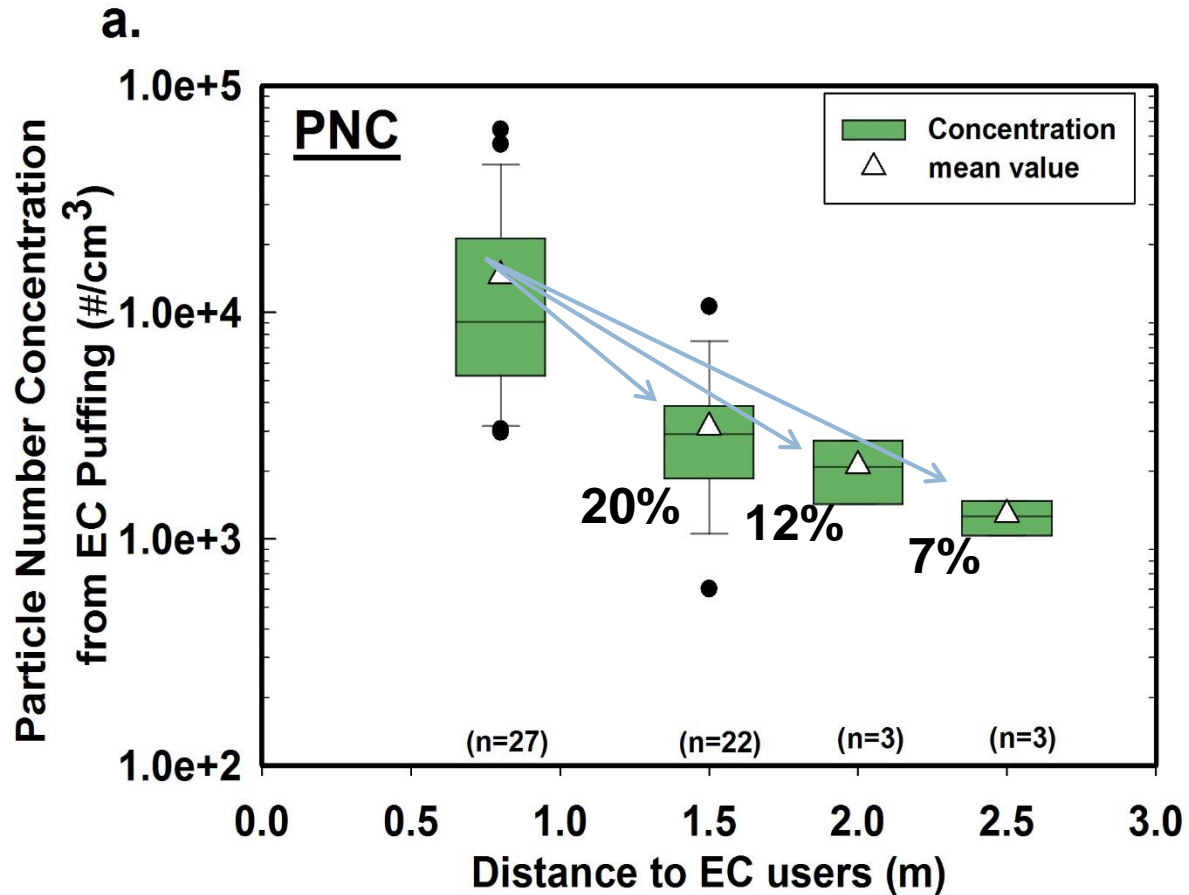
Long-term Exposure



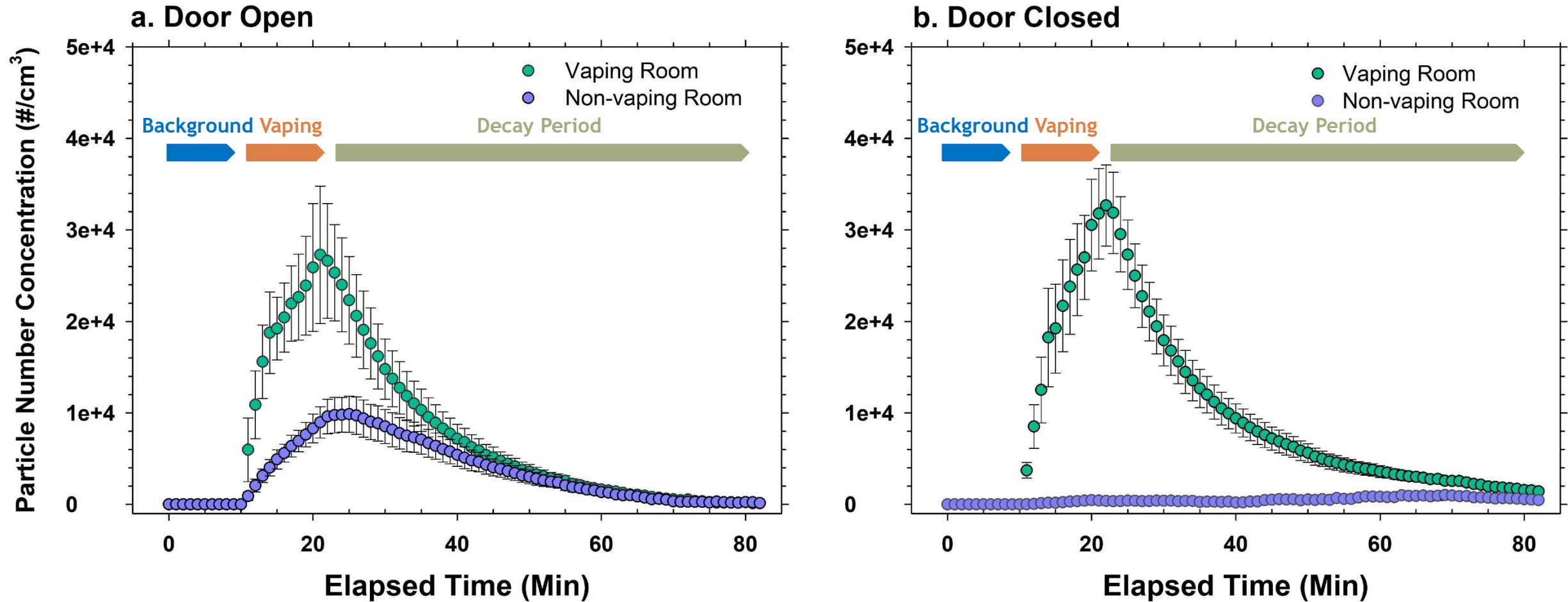
PM_{2.5} at 0.8 and 1.5 m away from e-cig users



Effects of distances to e-cig users



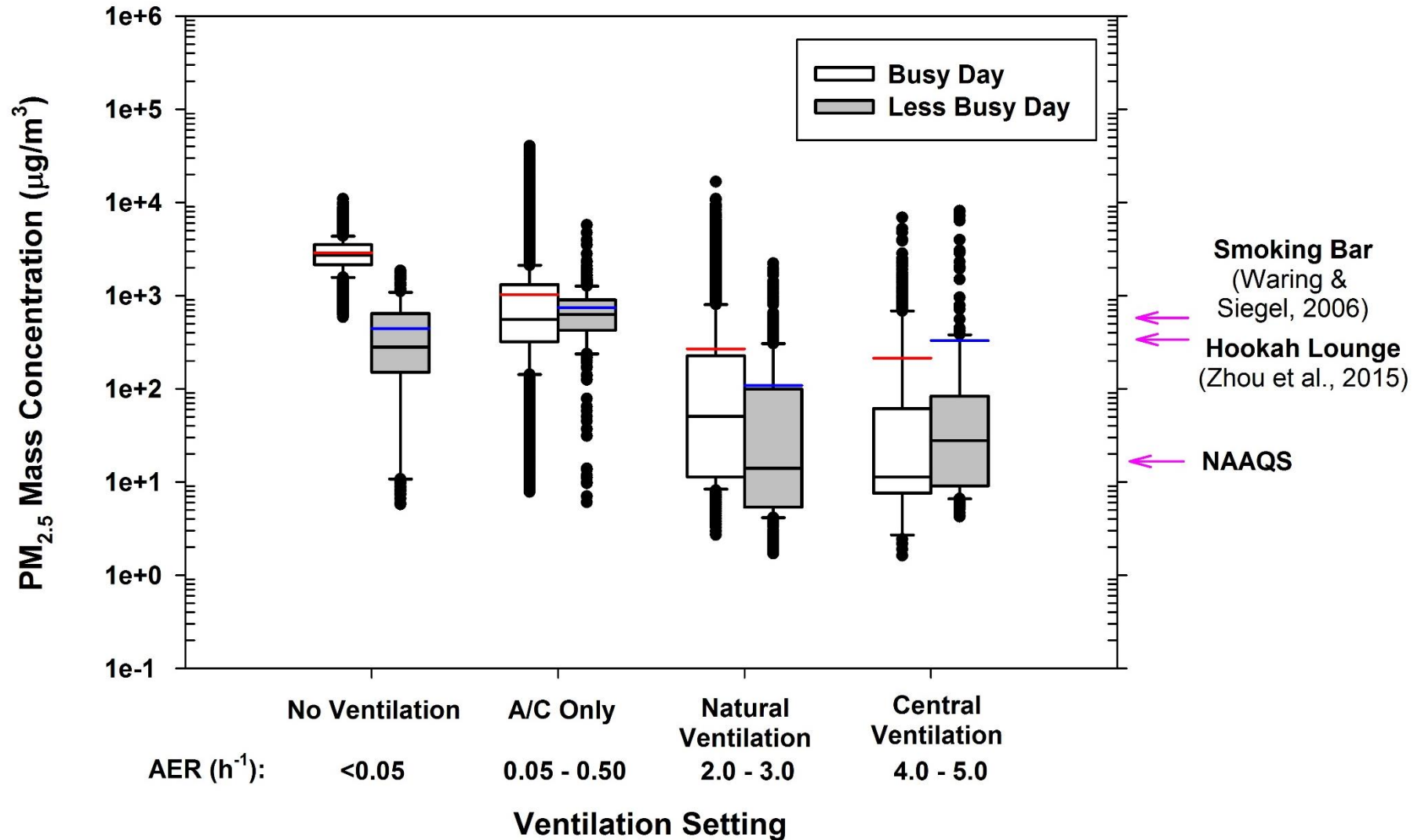
E-cig particles transport from a vaping room to a nearby non-vaping room



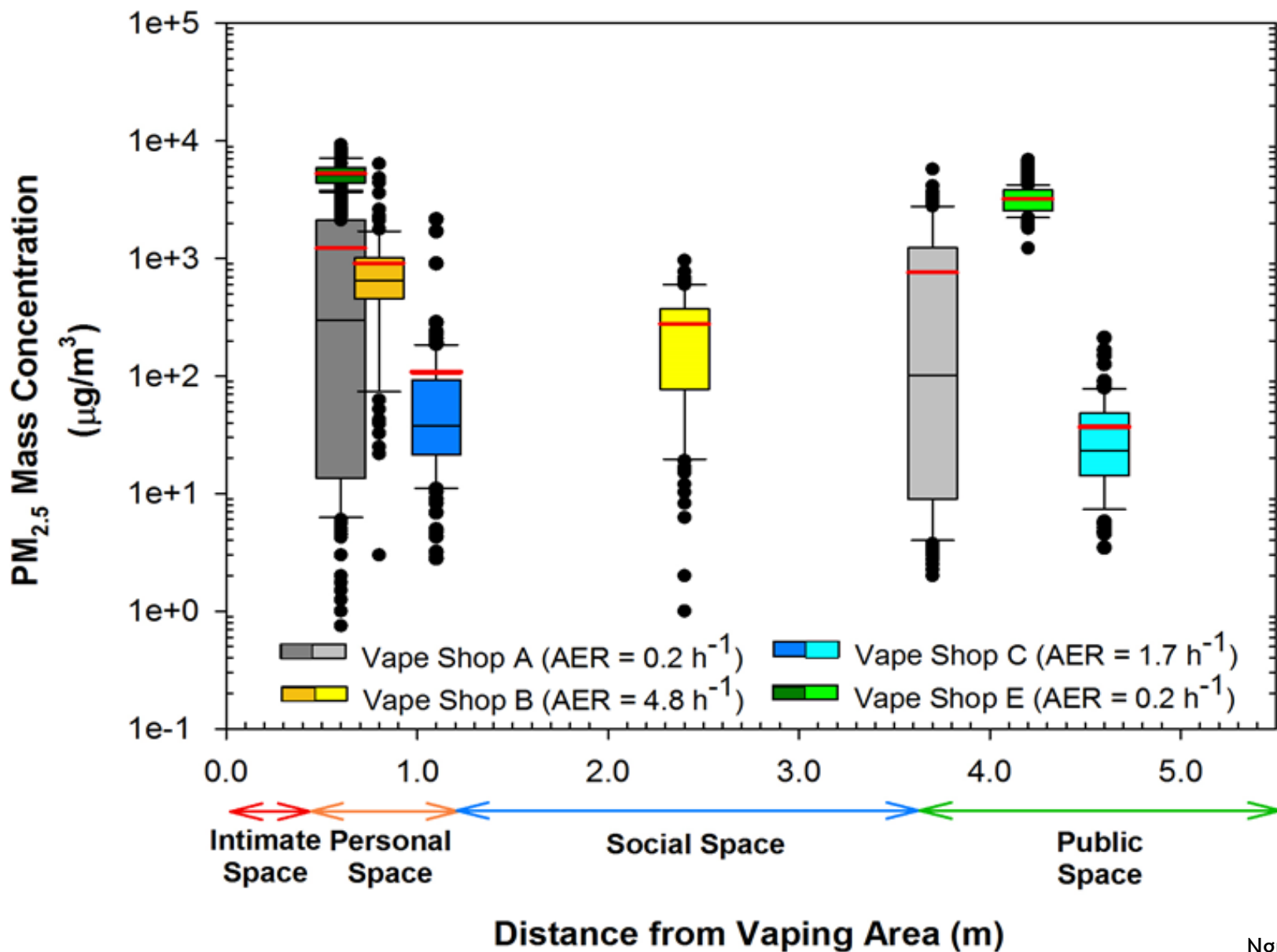
What's going on in Vape Shops



Vape Shop - PM_{2.5}



Vape Shop – Effects of Proximity from Vaping

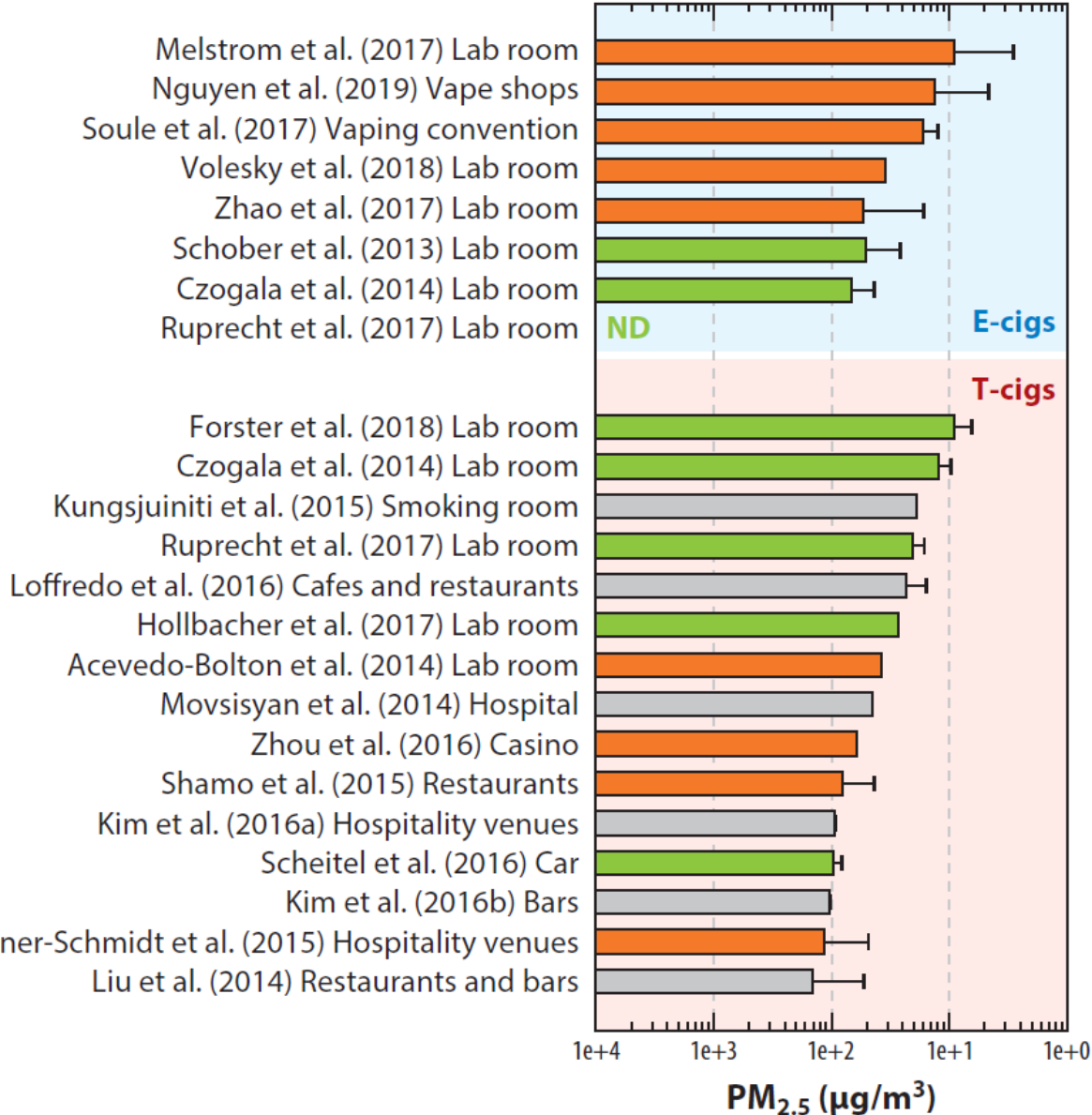


- Personal space (0.45 to <1.2 m)
- Social space (1.2 to <3.6 m)
- Public space (≥ 3.6 m)

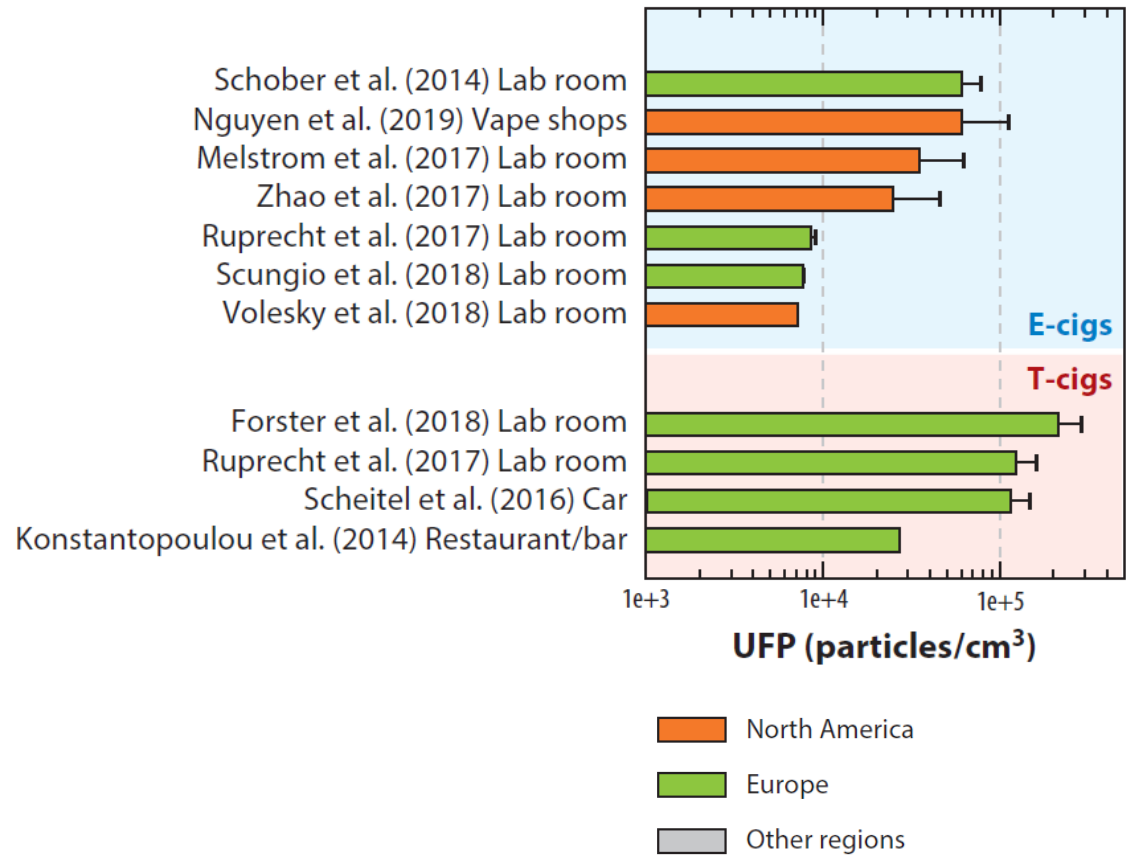


E-cigs vs. T-cigs – Impacts on Indoor Air Quality

a PM_{2.5}

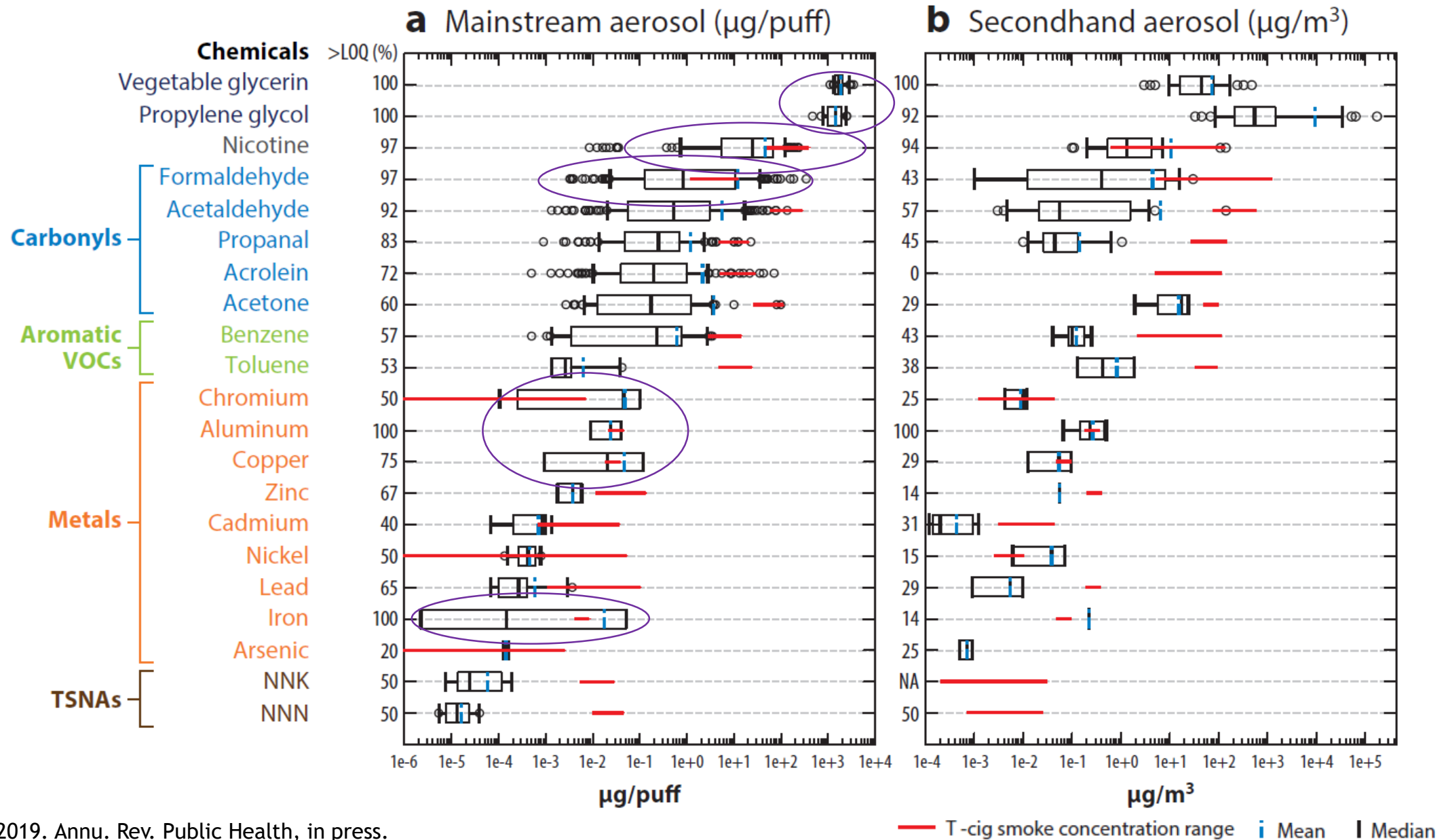


b Particle Number

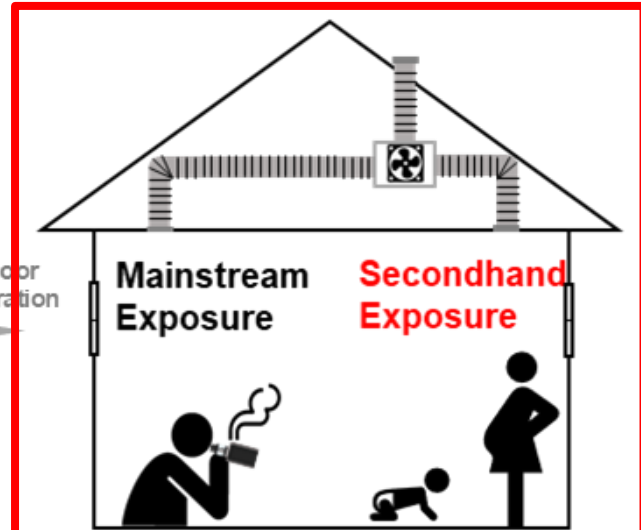
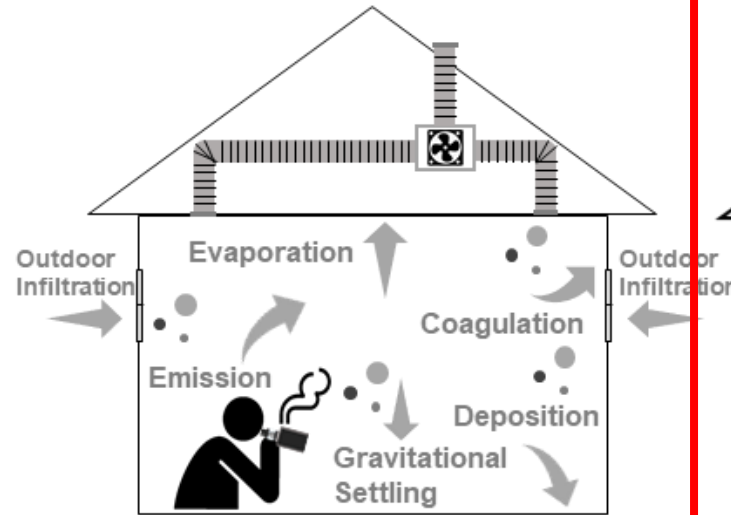
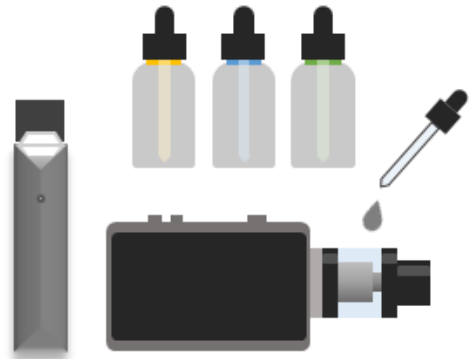


Li et al. 2019. Effects of Electronic Cigarettes on Indoor Air Quality and Health. Annu. Rev. Public Health, in press.

E-cigs vs. T-cigs – Chemical Composition



From E-cig emissions, to secondhand exposures, to potential health effects



Mainstream Emission

E-cigarette Device

- E-cigarette Type
- Power Voltage
- Heating Coil Temperature

E-liquid

- Propylene Glycol
- Vegetable Glycerin
- Nicotine
- Flavorings

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Puffing Topography

- Puff Duration
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Room Environment

- Dilution
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Health Effects

Short-term Exposure

- Respiratory
- Cardiovascular

Long-term Exposure



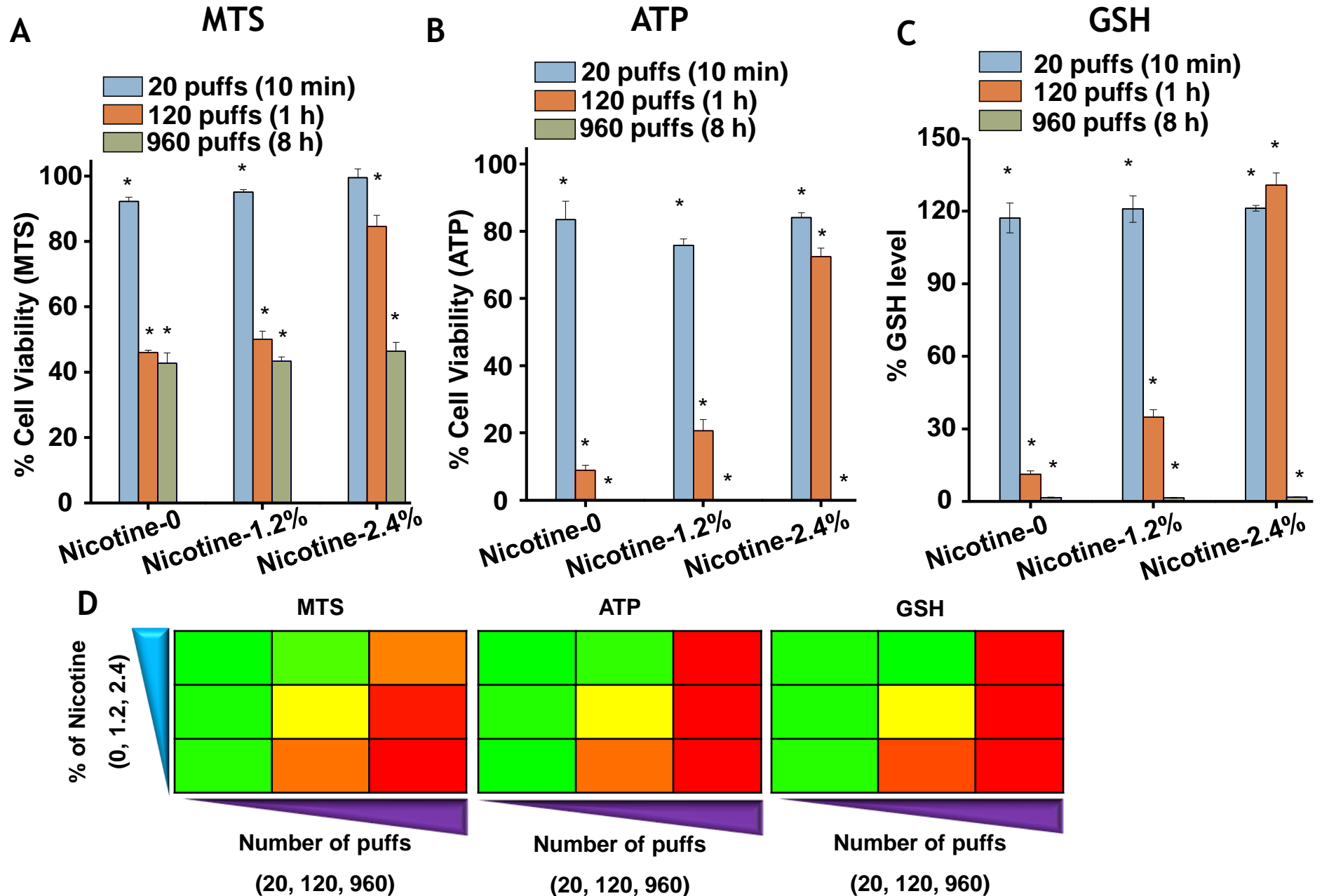
***In Vitro* Studies (Cell Studies)**

- Cytotoxicity (Farsalinos et al. 2013, Romagna et al. 2013)
- Inflammatory response, oxidative stress, cytokine release (Rubenstein et al. 2015)
- Decreased cell viability (Cervellati et al. 2014, Scheffler et al. 2015)
- Dose-dependent epithelial-cell death, reduced antimicrobial activity of macrophages (Hwang et al. 2016)
- Loss of endothelial barrier function (Schweitzer et al. 2015)

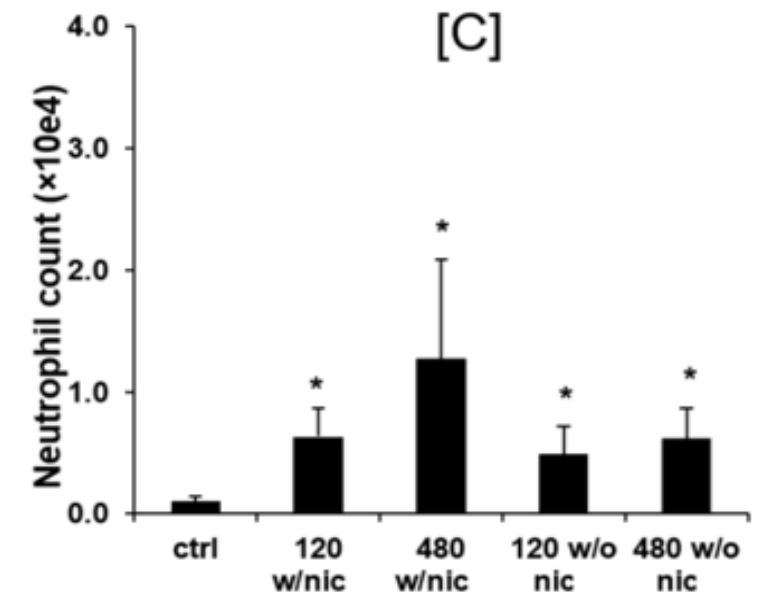
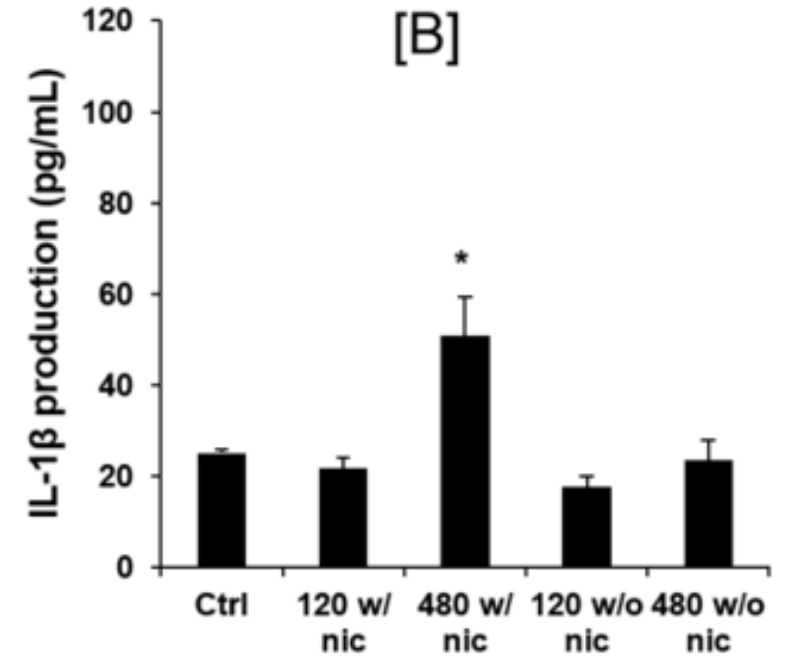
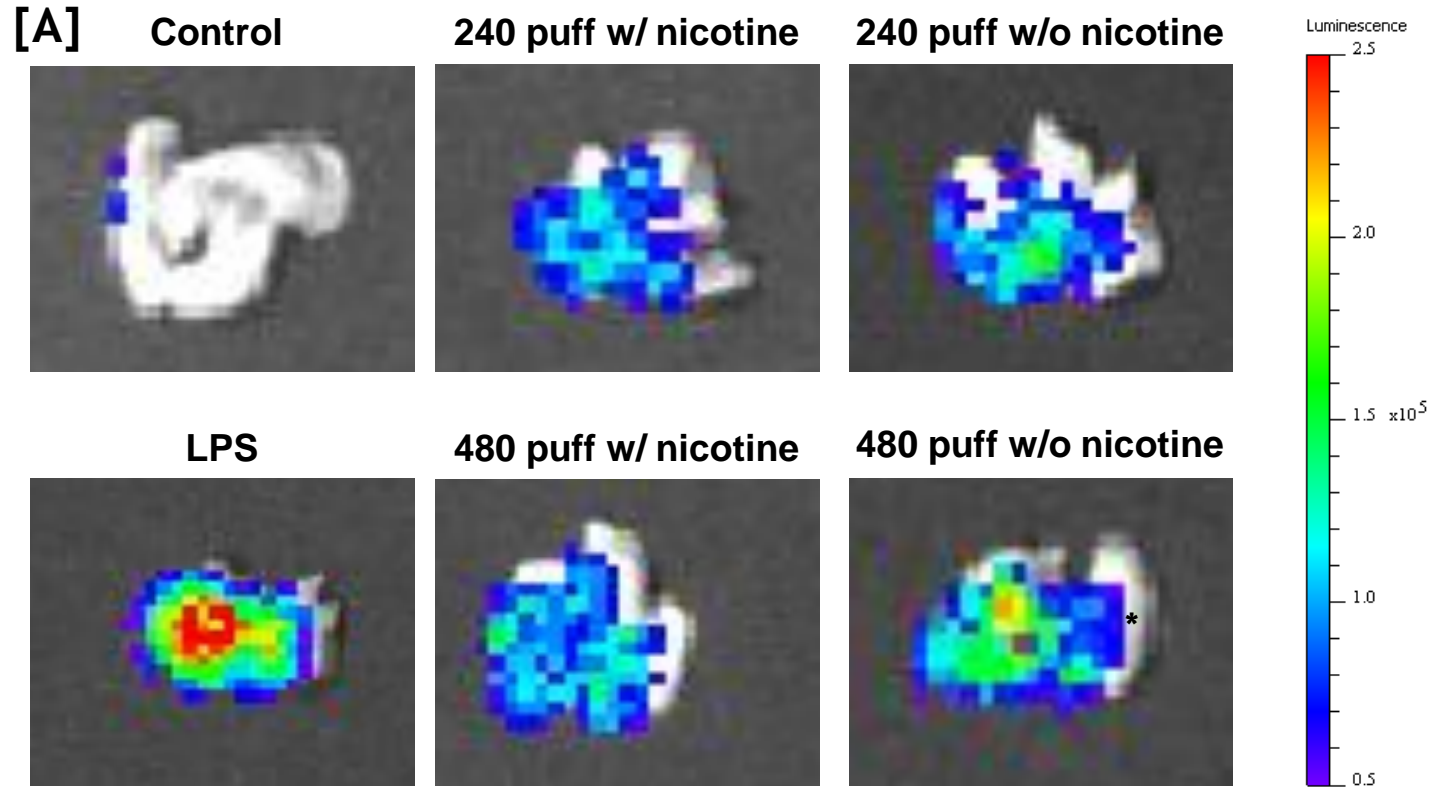
***In Vivo* Studies (Animal Studies)**

- Impair lung functions in animals, with inflammation and immune abnormalities as the likely underlying mechanisms (Dinakar and O'Connor. 2016)
- Perturb the cardiovascular system (Olfert et al. 2018, Qasim et al. 2018)
- Respiratory and cardiovascular effects (Crotty Alexander et al. 2018, Nguyen et al. 2018)
- Carcinogenicity and neurological toxicity (Lee et al. 2018, Nguyen et al. 2018)

In Vitro Case Study- Cytotoxicity



In Vivo Case Study



- E-cig aerosols can activate inflammatory pathway and induce stress responses in the lungs of animals [A]
- Results showed clear dose-dependent acute pulmonary effects in mice with high puff e-cig aerosols inducing more IL-1 β production [B] and neutrophil infiltration [C]

Effects on Human Health

■ Respiratory Effects

- Increase airway resistance (Vardavas et al. 2012, Tzortzi et al. 2018)
- Alter respiratory proteomic profiles among e-cig users indicative of impending airway obstruction (Dang et al. 2018)
- Asthma attacks and chronic bronchitis symptoms among adolescents (Kim et al. 2017, McConnell et al. 2017, Bayly et al. 2018)
- Inconsistent results on lung function measures (Ferrari et al. 2015, Flouris et al. 2013, Vardavas et al. 2012)
- Inconsistent results on airway inflammation after short-term exposures (Flouris et al. 2013, Antoniewicz et al. 2016, Ferrari et al. 2015, Marini et al. 2014, Schober et al. 2014, Tzortzi et al. 2018, Vardavas et al. 2012)

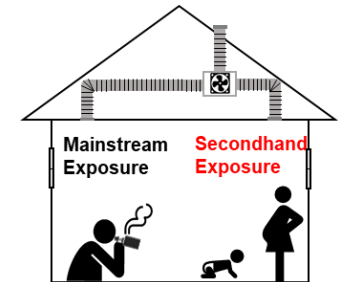
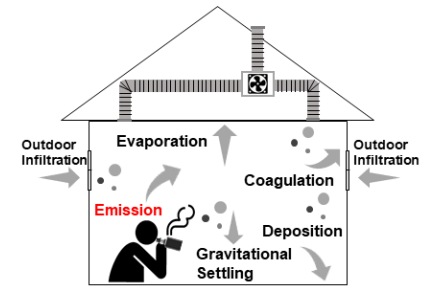
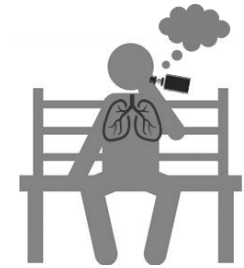
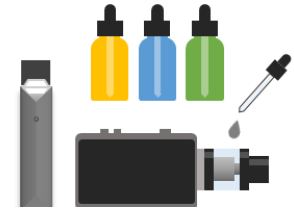
■ Cardiovascular Effects

- Cardiac-autonomic imbalance (i.e., heart rate variability) (Moheimani et al. 2017)
- Induce systemic oxidative stress and inflammation and impair endothelial function (Antoniewicz et al. 2016, Carnevale et al. 2016, Chatterjee et al. 2019, Moheimani et al. 2017)

Summary

■ The Knowns

- E-cig device, e-liquid parameters, and puffing topography substantially affect the e-cig aerosol emissions
- E-cigs degrade indoor air quality
 - Indoor particle levels from e-cigs are similar to t-cigs
 - Because e-cig particles are highly dynamic, they decay rapidly over distances (>1.5 m) from vaping at relatively ventilated condition; However, exhaled e-cig particles persisted in the high-vaping density, low-ventilation environment (i.e., vape shops)
- E-cigs produce substantial amounts of PG, VG, and nicotine, as well as some toxic compounds such as formaldehyde and heavy metals
- Respiratory and cardiovascular effects have been reported in animal and cell studies



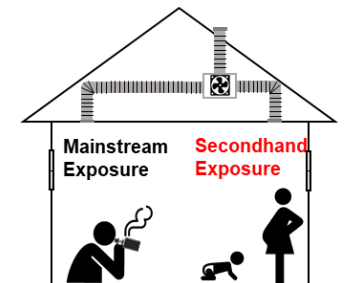
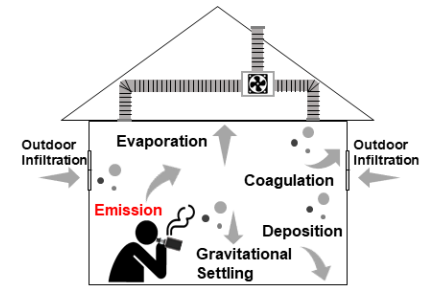
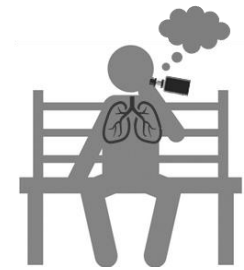
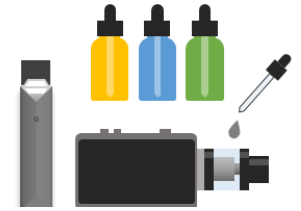
Summary

■ Known Unknowns

- The only commonality among all lung injury and death cases is that patients report the use of vaping products - the causes are largely unknown
- Contributing factors to the results observed *in vitro* and *in vivo* are unclear
- Current human studies focus on short-term acute effects but results sometimes are inconsistent
- Dosimetry of e-cig aerosols is poorly understood
- Limited studies on long-term human health effects

■ Unknown Unknowns

- We don't know what the next generation of e-cig would look like
- We don't know what people will DIY to vape with in the future



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THANK YOU!



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