Roadways in America

COMBATTING EMITTED VOLATILE ORGANIC COMPOUNDS FROM ASPHALT ROADWAYS

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CHEM/ENVS 328

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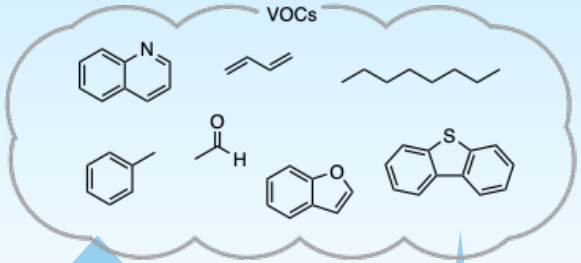
Introduction

American roadways have been a vital part of keeping the United States connected. Yet, this American infrastructure is something many take for granted, especially when we don't consider the material used to maintain the roads. Furthermore, as these roads begin to degrade over time from constant use, harmful Volatile Organic Compounds (VOCs) can be released into our atmosphere, contributing to adverse health and atmospheric effects.



Research Question

In order to conceptualize this project, we will need to ask ourselves a grounding question:

What role do American asphalt-based roadways play in VOC emissions in our atmosphere and what approaches have been developed to minimize their emissions?

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VOCs

Understanding VOCs is important to recognize their effects towards the atmosphere and our health. VOCs are a class of molecules that can show up in everyday life, but it is good to know that a few, like the one emitted from asphalt based roadways, are particularly harmful.

VOCs: What Are They?

Volatile Organic Compounds (VOCs) are carbon containing molecules that easily evaporate under standard conditions. This generally includes molecules with boiling points of ≤ 250°C.[1] This is interesting to note as they are able to reach our atmosphere through evaporation and it is very easy for living organisms to unknowingly become exposed to them.

Common VOCs are used in everyday life which includes chemicals such as acetone (found in nail polish remover) or ethanol (found in many cleaning products). Other VOCs include common solvents used in chemistry.

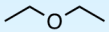
Ketones

Acetone

Alcohols

Ethanol

Ethers



Diethyl Ether

Halogenated Hydrocarbons

Dichloromethane

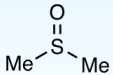
Alkanes

Hexane

Alkenes

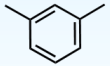
Isoprene

Organosulfurs



Dimethyl Sulfoxide

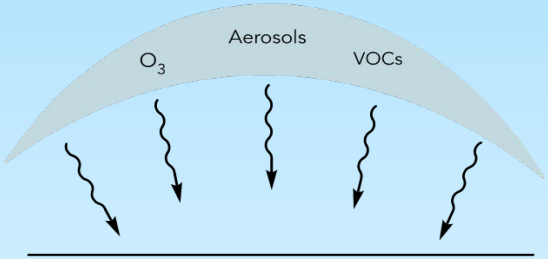
Aromatics



Xylene

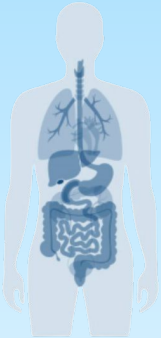
(1) Technical Overview of Volatile Organic Compounds; U.S. Environmental Protection Agency

VOCs: Environmental and Health Impacts



Atmospheric Effects

VOCs can have adverse effects on our atmosphere. Though they themselves are not greenhouse gases, they aid in the creation of them. Greenhouse gases trap heat in the Earth's surface and contribute to global warming and climate change.

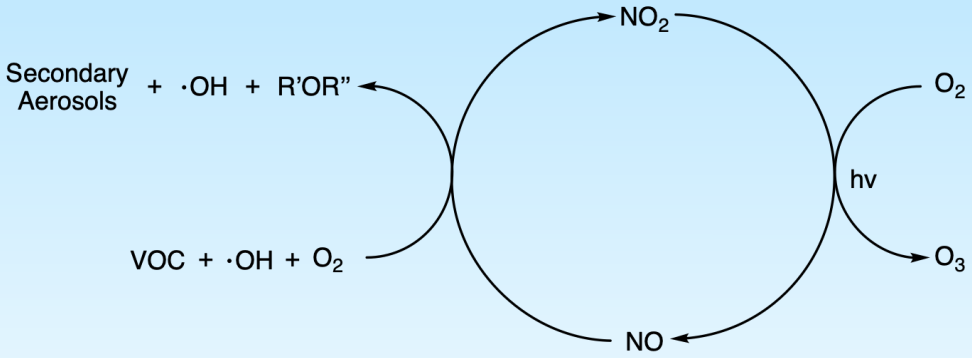


Health Effects

A few select VOCs are known human carcinogens and can damage organs. However, a majority of VOCs are irritants to the skin and lungs.

(2) Koppmann, Ralf. *Volatile Organic Compounds in the Atmosphere*; Blackwell Pub: Oxford

How Do VOCs Pollute?

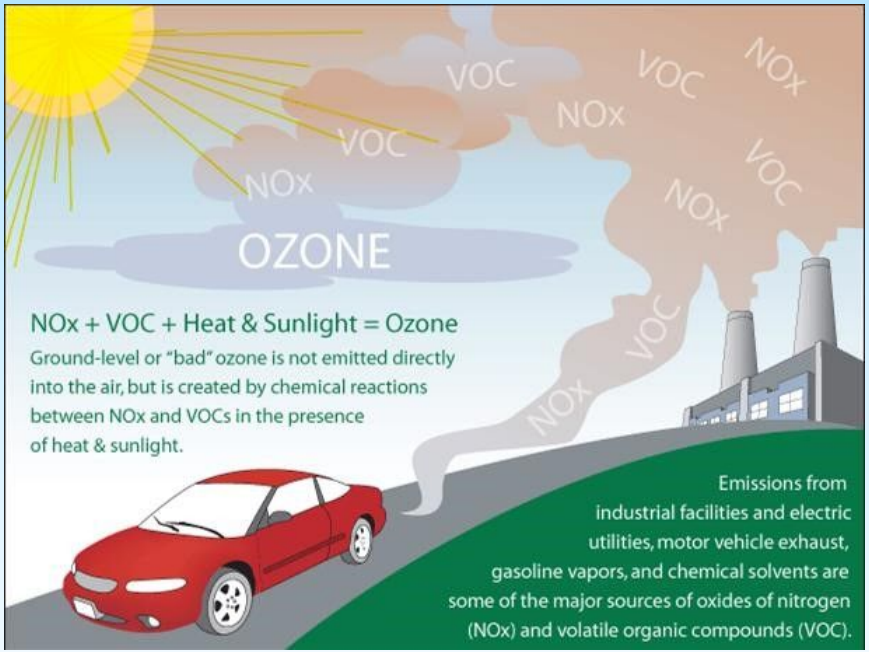


The science behind why VOCs are harmful to us and the environment is because they can react with certain molecules in the atmosphere. Compounds such as hydroxyl radicals (OH), oxygen gas (O_2), nitrogen oxide (NO) converts VOCs into aerosols, particulates in the air, as well as ozone which has detrimental health effects over long term exposure.

(2) Koppmann, Ralf. *Volatile Organic Compounds in the Atmosphere*; Blackwell Pub: Oxford

What's the Difference between Good and Bad Ozone?

It is important to understand the difference between good and bad ozone, and how VOCs play a role in creating bad ozone. Some VOCs play a role in creating surface-level ozone. When someone typically thinks of ozone, they think of the layer of ozone found in the stratosphere that helps absorb harmful UV rays from the sun. However, when ozone comes into contact with biological organisms around the surface of the earth, it can lead to respiratory and cardiovascular problems.



(1) Technical Overview of Volatile Organic Compounds; U.S. Environmental Protection Agency

3 American Roads

Now that we know a bit about VOCs, it is a great time to step back and discuss the prevalence of roads in America and in particular, asphalt-based roads. This will help give an idea of how impactful VOC emissions from asphalt-roadways are. Throughout this section, we will be answering a few questions you may have about American roads.

American Roads: How Are They Used?

How many miles of roads are in America?

America is comprised of 4.1- 4.3 million miles of roadway. [3, 4] These roads can be paved, unpaved, asphalt or concrete, and exist all across America. The figure to the right shows just a fraction of the roads that exist in the National Highway System. Of these 4.1-4.3 million miles, roughly 2.5 -2.7 million miles of road are paved and contribute to VOC emission.[4, 5]

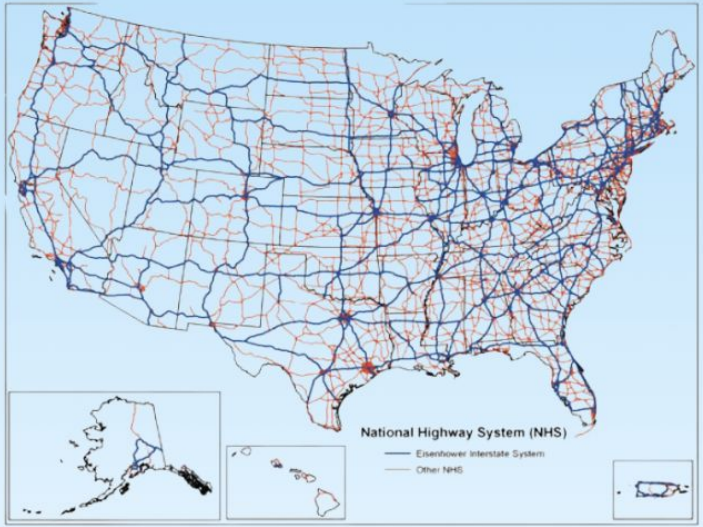


Figure 2. Map showing the National Highway System. Interstate highways are drawn in blue. Map from Federal Highway Administration (2006b).

How are these roads utilized?

We all know roads are used in America, but how much are they used? In 2023, the average American drove 13,476 miles per year.[6] This accounts for all types of commuting, as well as the interstate commerce systems that exist in the US.

(3)ASCE. *Roads*; ASCE's 2021 Infrastructure Report Card
(4)Potter, B. *How Good Are American Roads?*
(5)*Table HM-12 - Highway Statistics 2020 - Policy | Federal Highway Administration.*
(6)Federal Highway Administration. *Average Annual Miles per Driver by Age Group.*

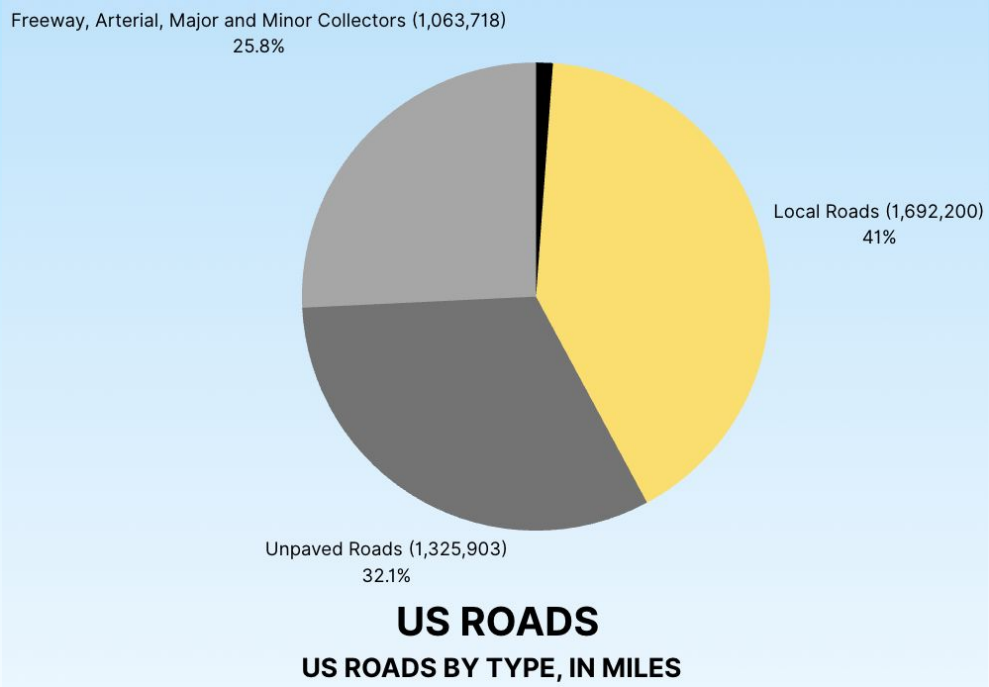
American Roads: How Are They Used and How Long do They Last?

What types of roads exist in America?

Let's delve deeper into the types of roads in America. Over 60% of the roads in America are paved.[3, 4, 7] As seen in the graphic to the right, they can be local roads, freeways, or interstate roads. Of these paved roads, over 96% of roads are asphalt roads.[7]

How long do roads last?

Asphalt roads can last between 15 - 20 years before they need to be resurfaced. Typically, interstate roads need to be resurfaced more often as they handle the heaviest volume of vehicles.



(3)Potter, B. *How Good Are American Roads.*
(4)Table HM-12. *Highway Statistics 2020;* Policy | Federal Highway Administration
(7)*Engineering - National Asphalt Pavement Association*

American Roads: What Are They Made of?

Natural Aggregates

Sand, gravel , and crushed stone make up the majority of paved roads. 60-75% of the volume of roads are made using these aggregates[8, 9]

Binders

Binder usually consist of asphalt (bitumen) and concrete that "bind" together the natural aggregates. Bitumen is a tar like substance that is derived from petroleum oil.[8] This is one of the main components of concerns with VOC emissions.

Modifiers

Modifiers are compounds added to asphalt and concrete roads. They are used to modify the properties such as the stiffness or flexibility and the climate adaptability of the roads.[8] America is made of diverse climates so roads in one part of the country, may not have the same properties as another.

(8) Longfellow, R. *Building Roads;* FHWA
(9) Federal Highway Administration, *Concrete Clips: Aggregates for Concrete Paving Mixtures*; USDOTFHWA

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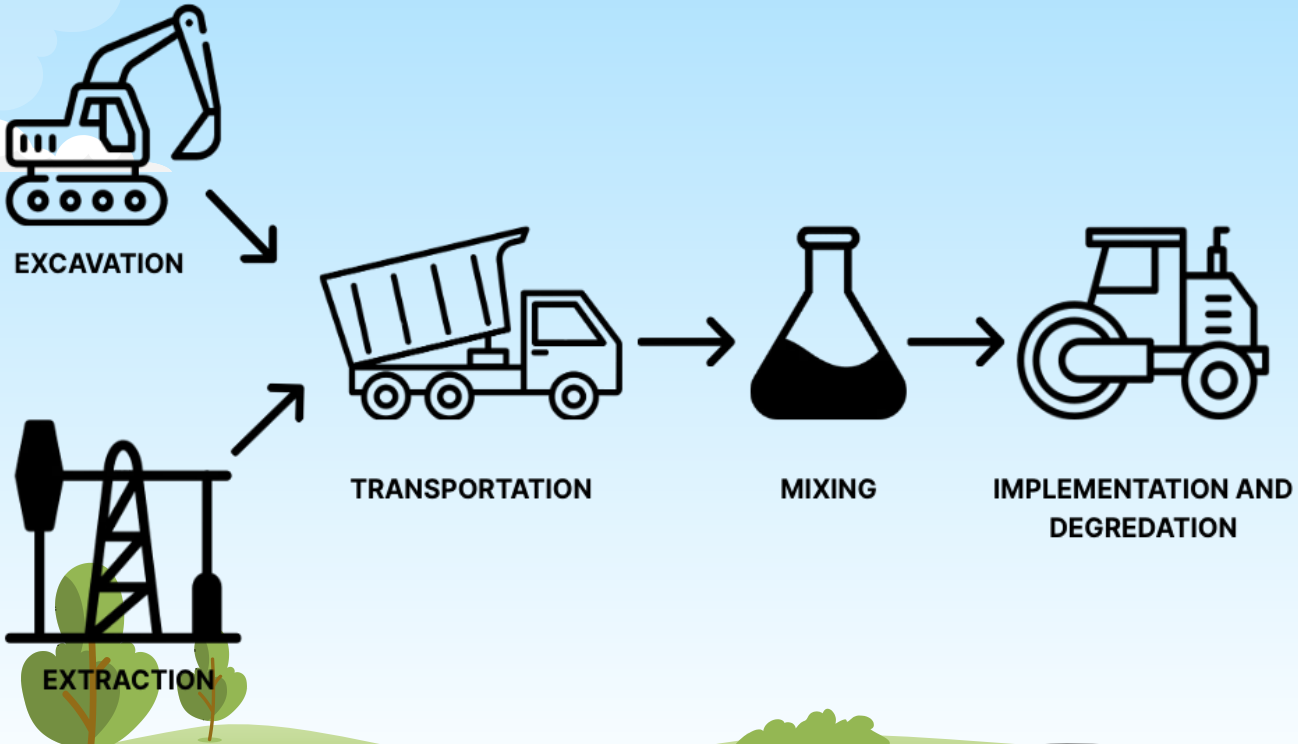
VOCs Emitted from Roadways

We can now move on to discuss the types of VOCs emitted from asphalt roads. This will give us insight into the conditions needed for these VOCs to be emitted during key processes like the manufacturing of asphalt and implementation in roads. We will also be able to show who is most likely to be harmed from VOC emissions.

Manufacturing Process



The creation of roads start from the cultivation of raw materials. The process begins with excavation of rocks, sand and gravel and extraction and refinement of crude oil into bitumen. These raw materials must then be transported and mixed at a high temperature to create a malleable product to be implemented, where it will degrade over time. All of these steps contribute to VOC emissions but the main step we will focus on will be the implementation and degradation.

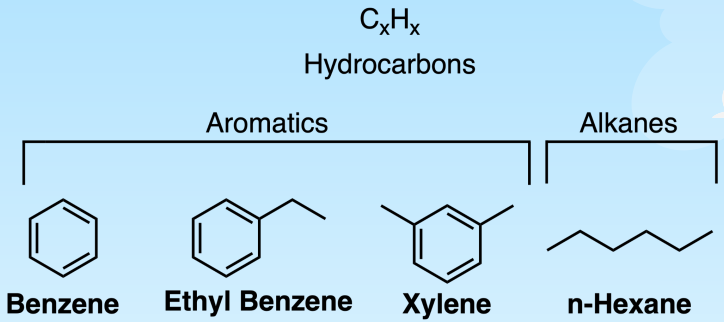
(10)Wang, F.; Li, N.; Hoff, I.; Wu, S.; Li, J.; Diego Maria Barbieri; Zhang, L. Characteristics of VOCs Generated during Production and Construction of an Asphalt Pavement. *Transportation Research Part D: Transport and Environment* 2020, *87*, 102517–102517.

VOCs from Implementation

Asphalt that is laid out to make roads comes in the form of hot mix asphalt. The asphalt is heated to about 150°C to make more malleable so that it can be easily applied.

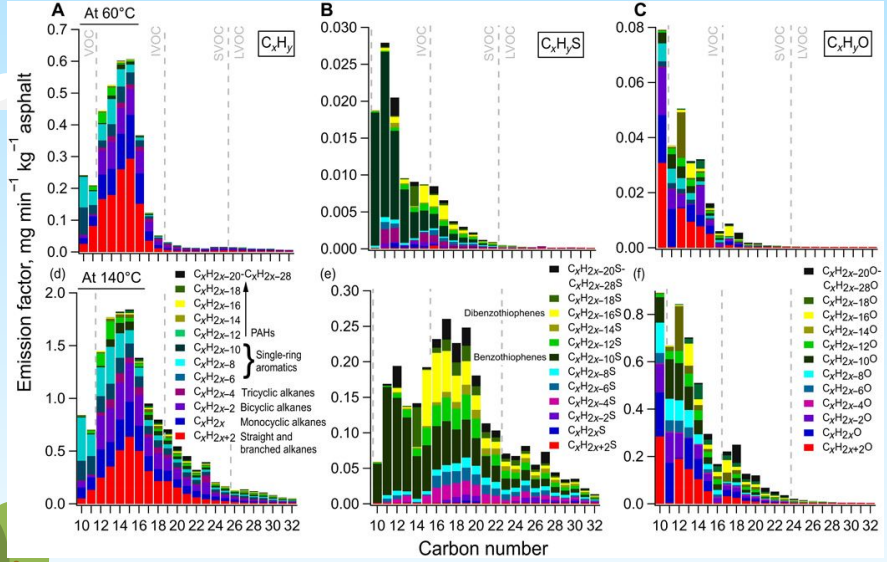
More than 30 VOCs are emitted from asphalt during the implementation phase of roadways. Some of these VOCs are hydrocarbons, and a particular hydrocarbon, benzene, is considered a carcinogen.

These VOCs are particularly problematic for the workers who lay out the nearly 150° C asphalt.



(11) Liu, G; et al. Effect of Heating History on the Emission of Volatile Organic Compounds from Asphalt Materials. *Sci. Total Envi.* 2023
(12) Gentner, D. R; et al. Asphalt-Related Emissions Are a Major Missing Nontraditional Source of Secondary Organic Aerosol Precursors. *Sci. Adv.* 2020

Relationship between Asphalt Temperature and VOC Emissions



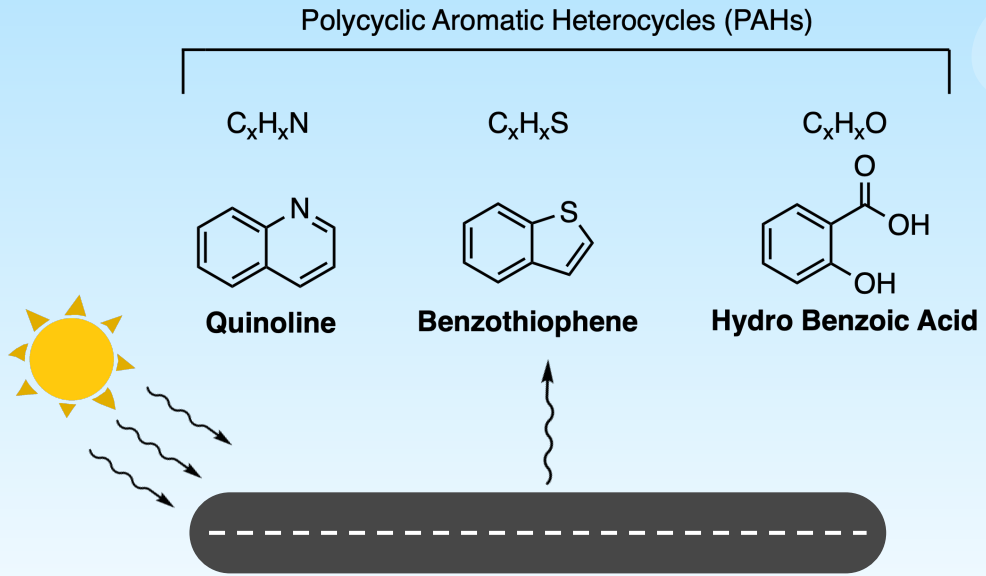
According to the figure, it shows how VOC emissions increase when heating asphalt mixtures. So, VOC emissions are highest when asphalt is first being laid out but still continue to emit VOCs even at ambient temperatures.

Asphalt releases a wide variety of VOCs such as CxHy which are hydrocarbons, CxHyS are sulfur compounds, and CxHyO are oxygen containing compounds.

(11) Liu, G; et al. Effect of Heating History on the Emission of Volatile Organic Compounds from Asphalt Materials. *Sci. Total Envi.* 2023

VOCs from Degradation

Though the implementation asphalt releases a lot of VOCs, VOCs are also emitted over the lifetime of the road. Emissions of VOCs increase through heating and UV irradiation from sunlight. This means that sunlight degrades roadways over time. It can be concluded that roadways still emit VOCs even after implementation.



(12) Gentner, D. R; et al. Asphalt-Related Emissions Are a Major Missing Nontraditional Source of Secondary Organic Aerosol Precursors. *Sci. Adv.* 2020

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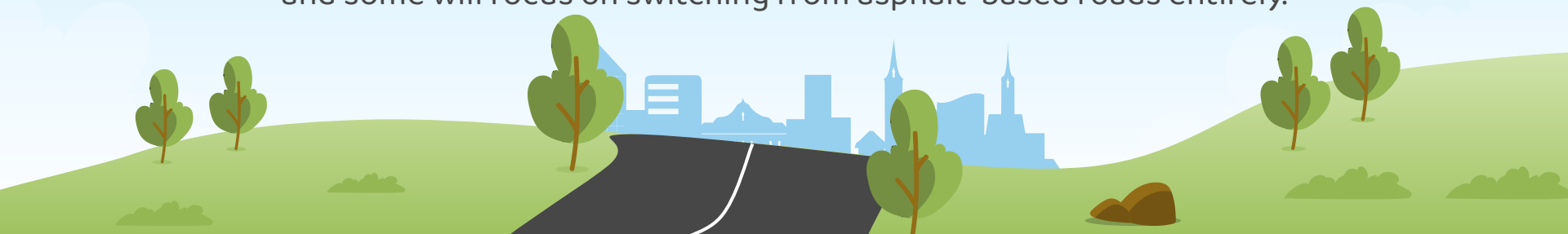
Strategies for Dealing with VOCs

Finally, this section will look at strategies scientists and environmental policy makers are developing that deal with VOC emissions from asphalt roads. Some methods will focus on combating these emissions at the implementation phase, others in the degradation phase, and some will focus on switching from asphalt-based roads entirely.



VOC-Inhibiting Construction Methods

Reducing Asphalt Temperature

A method to reduce VOC emissions from hot mix asphalt involves using a lower temperature mix of asphalt.

Warm mix asphalt, which is heated to 90-120°C, can be used instead. Since VOC emissions is correlated with temperature of the asphalt, this would decrease exposure of VOCs towards workers during construction.

Water Cooling Asphalt

Another strategy that can be used is spraying high pressure water towards newly laid asphalt to suppress their emission.

This would decrease the temperature of the asphalt and decrease the amount of fumes emitted.

It would reduce exposure of VOCs towards workers.

(14) Cui, Q.; et al. VOC Emissions from Asphalt Pavement and Health Risks to Construction Workers. *J. of Cleaner Production.* 2019

VOC-Inhibiting Modifiers

Biochar

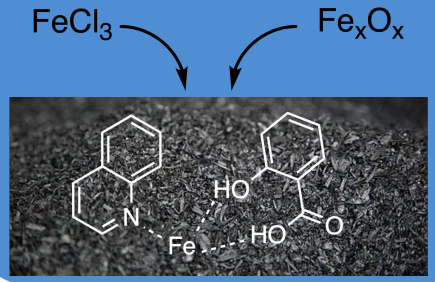
Biochar, a type of charcoal obtained by heating biomass, is mixed into asphalt to adsorb VOCs.

The porous nature enables inhibition of VOC emissions from roadways.

Fe-Rich Biochar

Recently, earth abundant transition metals have been studied in their ability to bind to VOCs.

Iron has been mixed in with biochar and has been able to bind and inhibit emission of PAH VOCs.



Geopolymers

Geopolymers is a ceramic-like polymer made from mixtures of SiO_2, Al_2O_3, MgO, CaO, etc.

Can be added to asphalt mixtures to adsorb VOCs and aerosols.

(15) Fini, E. H.; et al. Investigation of Earth-Abundant Metal Salts for the Inhibition of Asphalt-Derived Volatile Organic Compounds. *ACS Omega.* 2024
(16) L.; Wang, Q. Reduce VOCs and PM Emissions of Warm-Mix Asphalt Using Geopolymer Additives. *Construction and Building Materials.* 2020

Conclusion

VOCs are volatile molecules that easily evaporate and are found in our everyday lives. A significant source of VOCs have be found to originate from the manufacturing, implementation, and degradation of asphalt roads. VOCs have been studied to have negative environmental and health impacts.

A wide variety of hydrocarbons, sulfur-containing, and oxygen containing VOCs are released by bitumen, the binding component of asphalt. As asphalt is heated, more VOCs are emitted which poses health risks towards workers. Even after asphalt is laid out, VOCs are still emitted.

Strategies and policies have been developed to inhibit VOC emissions such as use of biochar and other materials to adsorb VOCs, switching from asphalt to concrete, or reducing the temperature of asphalt to reduce VOC emissions.

Switching from Asphalt to Concrete

As opposed to asphalt roads that last 15-20 years, concrete roads typically last 20-40 years. Due to increased longevity, roads do not need to be repaved as often, reducing VOC emissions compared to asphalt. Many states have seen this shift from asphalt roads to concrete roads, like the state of California.

(13) Fell, Andy. *Pavement Research Center Keeps California On The Road*; UC Davis

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