Report to the Legislature

Interagency Carbon Monoxide Work Group

December 2024

SHB 1779 – 2023-24

School Environmental Health & Safety and Indoor Air Quality Program

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Executive Summary

Chapter 310, Laws of 2023 tasked an interagency carbon monoxide (CO) work group to develop a report detailing actions to prevent CO poisoning from sources outside the home; increase awareness of at-risk groups; collect data on incidents and causes to track exposure reduction; and to identify funding opportunities. The work group met monthly starting September 2023, to gather information and discuss data.

CO is a poisonous, odorless, and tasteless gas formed from burning materials such as gas and liquid fuels, charcoal, and wood. Chronic, low-level CO exposures may cause headaches and increased risk of cardiovascular health impacts. Higher levels of CO cause cognitive and neurological impairment, serious cardiovascular impacts, seizures, coma, and death, sometimes in minutes.[1,2,3,4] Unintentional CO poisonings are preventable but cause more than 10 deaths every year in Washington.[5] The CO exposure death rate has risen between the 2010s and 2020s in Washington, in other states, and the U.S., but the cause is not clear.[6,7]

The work group found that current datasets somewhat indicate how people are impacted by CO exposure, but few show at-risk populations or undergo regular review for emerging patterns. There is no cohesive tracking across datasets.

Groups with higher observed CO exposure rates in Washington include people who are: middle-aged; male (sex); identifying as "Other Race"; working in occupations that require the use of, or proximity to, fuel-burning devices; and in temporary dwellings such as trailers, campers, motor homes, vehicles, tents, trucks, or vans (such as people who are unhoused).

The work group identified four main causes of unintentional CO poisonings in Washington:

- Exhaust from motor vehicles and gas or diesel engines
- Exhaust from fuel-powered heating and cooking devices, including wood stoves
- Fuel-powered tools and equipment, including generators
- Fuel-powered appliance malfunctions, including gas stoves

[1] WHO Guidelines for Indoor Air Quality: Selected Pollutants (see page 55 for CO).

[2] Yoon, S. S., *et al.* (1998). *J Amer Med Assoc*, *279*(9), 685-687. doi:10.1001/jama.279.9.685.

[3] Toxicological Profile: CO (ATSDR). Other health effects are shown in rodents but are not summarized here. Some associations with health problems may be confounded by co-exposure to other air pollutants.

[4] Carbon Monoxide's Impact on Indoor Air Quality (U.S. EPA)

[5] Based on data from the Washington Tracking Network: Carbon Monoxide Data (Washington DOH).

[6] Hampson, N. B. (2023). *Clinical Toxicology, 61*(7), 483-91. doi: 10.1080/15563650.2023.2237667

[7] Topping, J. (Feb 2024) Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products 2020 Annual Estimates (PDF).

Work Group Recommendations

The work group offers the following current and recommended future state agency activities, policy options, and other actions to reduce CO poisoning in Washington:

(a) Prevent CO poisoning from sources outside of the home: Washington agencies, in collaboration with the University of Washington Department of Environmental and Occupational Health Sciences, should study the measurement capability and utility of portable CO monitors.

(b) Increase awareness of CO among the most at-risk populations: DOH should build a CO exposure prevention toolkit for community-based organizations and local health partners.

(c) Collect data on the number of incidents of CO poisoning and their causes and track the reduction of incidents over time: Washington state would benefit from bringing together an ongoing committee of state agencies and organizations to review data and develop timely messaging.

(d) Funding opportunities for public awareness campaigns related to CO harm avoidance: The work group found limited resources available to raise awareness on CO harm avoidance outside the home.

Further work group recommendations on new policy options and other actions that could be taken to reduce CO poisoning: Washington state has the ability to take stronger positions in support of policy and legislative decisions would result in health co-benefits. For example, the health co-benefit of eliminating CO emission sources should be elevated when legislative and policy decisions are made.

Work Group Members and Priorities

Work Group Members

- Washington State Department of Health (Washington DOH): Ali Boris (chair), Juan Gamez Briceño, Nancy Bernard
- Washington State Department of Ecology (ECY): Gary Palcisko
- Washington State Patrol (WSP): Jennifer Nuse
- Washington State Office of the Attorney General: Manveer Sandhu
- Guest subject matter experts: Washington Department of Labor & Industries (L&I): Todd Schoonover, Carolyn Whitaker

Work Group Directive and Activities

Directive: State agencies were directed to "…collaborate on a study of what Washington state is doing to prevent carbon monoxide poisoning from sources outside of the home and what the state might reasonably do to keep people safe." The work group was tasked with writing a report to contain, "…recommendations on new policy changes and other actions that could be taken to reduce carbon monoxide poisoning in Washington."[8] Specifically, the legislature directed the work group to recommend activities that would:

(a) Prevent carbon monoxide poisoning from sources outside of the home.

(b) Increase awareness of carbon monoxide among the most at-risk populations.

(c) Collect data on the number of incidents of carbon monoxide poisoning and their causes in Washington, in order to track the reduction of such incidents over time; and

(d) Identify any opportunities to seek federal grants or other sources of funding available for public awareness campaigns related to carbon monoxide harm avoidance.

Focus: CO exposure data are not always delineated into exposures "outside" versus inside the home. All unintentional, non-fire related incidents in available CO exposure datasets were reviewed for the report. However, the work group's recommendations focus on exposures outside the home. The work group defined exposures "outside the home" as those that occur in spaces other than houses or residential buildings where CO alarm requirements exist.

Activities: The work group met monthly starting September 2023 (except March 2024). The work group gathered information from organizations and partners throughout Washington state and at the federal level. We discussed data, communications, and report plans at meetings and provided expert insights and gathered relevant information from their agencies. Washington DOH and L&I

[8] Washington House Bill 1779 2023-2024

gathered and reviewed exposure and health effects datasets, and shared findings with the work group.

Work Group Priorities

In accordance with SHB 1779 23-24, the work group agreed on the following priorities:

- Identify the most frequent causes of CO poisoning in Washington.
- Identify at-risk populations for CO poisoning in Washington.
- Identify Washington CO poisoning datasets collected and ask whether there are sufficient existing poisoning tracking programs.
- Recommend activities to prevent CO poisoning from sources outside the home and increase awareness among the most at-risk populations.
- Identify funding opportunities for public awareness campaigns related to CO poisoning prevention.

Background

What is Carbon Monoxide (CO)?

Carbon monoxide (CO) is a poisonous, colorless, odorless, and tasteless gas, sometimes called the "invisible killer." CO forms from the incomplete burning of material containing organic carbon atoms, especially with a hydrocarbon molecular structure, such as natural gas (methane), propane, gasoline, diesel, kerosene, charcoal, wood, or most plastics.

Common symptoms of CO poisoning include headache, nausea, weakness, dizziness, confusion, fatigue, changes in personality, and loss of consciousness.[4]

In Washington state, more than 10 people die every year due to unintentional, non-fire-related CO exposure, and more are hospitalized.[5] Across the U.S., about 500 people die every year due to unintentional, non-fire-related CO exposure.[6,9] Exposures occur during personal time as well as on the job. CO was the leading cause of valid workers' compensation injury claims due to toxic exposures, out of eight priority inhaled substances, in Washington (*n*=389 cases, 2017-2020).[10] Examples of CO exposures in the workplace were in recent news:

- *In 2017–2019, officers from the WSP and other law enforcement agencies reported exposures to CO while in their patrol cars. Local and national Investigations revealed exhaust leaks.*[11]
- *In 2023, a truck driver died from CO poisoning after a rest break in his truck's sleeper berth. Investigators found that the driver was using a butane cooking stove in the truck.*[12]

[9] EPH Tracking (CDC NEPHTN)

[10] Surveillance of toxic inhalation for Washington workers, 2017 – 2020 Report (L&I, PDF)

[11] WSP Responds to Ford CO Probe (WSP blog)

[12] Truck Driver Poisoned by CO (L&I FACE, PDF)

Poisoning Mechanism

When inhaled, CO passes through the lungs and into the blood stream, where it binds to hemoglobin, the protein that normally carries oxygen (O_2) through the body. The bond between hemoglobin and CO is more than 200 times stronger than that with O_2, and CO remains bound to hemoglobin for longer than O_2. As CO displaces O_2 in the blood, a low O_2 concentration in the body's tissues, called hypoxia, results. For chronic effects, there may be other unidentified mechanisms that do not involve binding with hemoglobin.[1]

Health Effects

Health effects associated with CO poisoning can include:[1,3,4]

- Chronic exposures at low concentrations (<70 ppm): headaches; balance and cognitive difficulties; asthma exacerbation; and increased risk of heart attack, stroke, congestive heart failure, and coronary artery disease.
- At high concentrations (>70 ppm): visual and auditory sensory effects, cognitive and neurological impairment, cardiovascular disease exacerbation.
- Acute exposures at very high concentrations (hundreds to thousands of ppm): seizures, coma, and death.

Many CO poisonings are misdiagnosed because other health problems have similar symptoms.[1]

Existing Exposure Guidelines

Based on available exposure studies and models, exposure concentration thresholds have been established for CO, including indoor requirements for workplaces and guidelines for "normal adults", which are summarized in Table 1. Outdoor (ambient) standards are also included.

In Washington, employers must follow the Permissible Exposure Limits (PELS) for airborne contaminates established by the Washington Industrial Safety and Health Act (WISHA).

For reference, CO building alarms following UL standard 2034 must alarm at 70 ppm over 60–240 minutes, 150 ppm over 10–50 minutes, and 400 ppm over 4–15 minutes (but must not alarm before 60 minutes at 70 ppm or 30 days at 30 ppm).[13]

[13] UL Standards & Engagement: UL 2034 (UL); thresholds based on a model of uptake; see Appendix B: Building Codes, CO Alarm and Detection Requirements for more.

Table 1. Indoor and outdoor CO exposure guidelines for workplace exposures (purple) and for "normal adults" (orange), in parts CO per million parts air by volume (ppm).

Time Interval	WISHA PEL[14]	OSHA PEL[15]	NIOSH REL[16]	ACGIH TLV[17]	WHO Guideline[18]	NAAQS (Outdoor)[19]
24 hours	--	--	--	--	7	--
10 hours	--	--	35	--	--	--
8 hours	35	50	--	25	9	9
1 hour	--	--	--	--	31	35
15 minutes	--	--	--	--	87	--
Ceiling Value	200	--	200	--	--	--
IDLH	1500	--	1200	--	--	--

Note: Time interval is the length of time to which the standard applies.

Note: Conversion for WHO Guideline: at 760 millimeters mercury and 25°C, 1 milligram per cubic meter = 0.873 ppm CO.[1]

CO Poisoning Prevention

Washingtonians experience an average of 190 poison center calls, 300 emergency department visits, at least 16 hospitalizations, and 15 hyperbaric treatments associated with CO exposure every year.[20] Despite these numbers, CO poisonings are entirely preventable through directed messaging and control measures.

CO inhalation poisoning is challenging to prevent because CO is impossible to sense and can come from combustion of many substances.

The risk of CO exposures is growing. Factors include increasingly tightly constructed buildings, which can allow pollutants to accumulate indoors, and the growth of technologies such as keyless

[14] A WISHA PEL ceiling concentration for CO is an average over five minutes. Immediately Dangerous to Life and Health (IDLH) indicates "a maximum concentration above which only a highly reliable breathing apparatus providing maximum worker protection should be permitted." WAC 296-841-20025: Airborne Contaminants – PELs. Historical Documentation – IDLH, CDC

[15] OSHA is the federal Occupational Safety and Health Administration.

[16] National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit (REL) indicates time weighted average (TWA) limits up to a 10-hour workday in a 40-hour workweek. NIOSH REL ceiling based on risk of cardiovascular effects; no exposure should be allowed for even a short amount of time. Pocket Guide to Chemical Hazards Introduction (NIOSH)

[17] American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) concentration, "for a conventional 8-hour workday and a 40-hour workweek, to which it is believed that nearly all workers may be repeatedly exposed, day after day, for a working lifetime without adverse effect." TLV Chemical Substances Introduction - (ACGIH)

[18] World Health Organization (WHO) Indoor CO guideline for 15 minutes and one hour: should not occur more than once per day, during light exercise. WHO Indoor CO guideline for 8 hours is an arithmetic mean, applicable during light to moderate exercise. WHO Indoor CO guideline for 24 hours is an arithmetic mean, applicable while awake and alert but not exercising. WHO Guidelines for Indoor Air Quality: Selected Pollutants (see page 55 for CO).

[19] National Ambient Air Quality Standard (NAAQS) are outdoor standards set by U.S. EPA. For CO, standards are intended to protect, including for "sensitive" populations, and may not be exceeded more than once per year. NAAQS Table (U.S. EPA).

[20] Averages: non-fire Washington Poison Center calls 2013-2023, non-fire, unintentional RHINO ED visits May 2020-May 2023, non-fire, unintentional NEPHTN hospitalizations 2012-2021, non-fire, unintentional or unknown intent Virginia Mason hyperbaric visits 2013-2023. See Appendix A: CO Exposure Datasets, Tracking, and Attributed Sources.

ignition vehicles, which can start a car parked in a garage from a distance. Climate change has also increased the frequency and duration of power outages due to weather events,[21] the time spent in conditioned spaces, and direct exposures to wildfire smoke, which can contain CO.[22]

While we cannot detect CO without a device, unintentional CO poisonings are preventable by:

- Increasing public awareness about common CO sources and how to prevent exposures.
- Identifying and removing or replacing common CO sources.
- Improving technologies to prevent leaks and accumulation of CO.
- Installing CO sensors, alarm systems, or both on devices and near CO sources.

CO Exposure Datasets and Tracking in Washington

Summary

Together, current national and state datasets collected can be used to show CO exposure impacts in Washington. However, only some datasets include information needed to identify at-risk groups, such as ethnicity, race, sex, gender, location, date, and source of exposure.

While there are programs actively tracking workers' exposures, tracking of other CO exposures for emerging patterns and causes is a gap in Washington state.

Currently, CO exposure data collection, and active tracking, are done by multiple separate programs without interaction.

Designating CO poisoning as a notifiable condition in Washington state would likely achieve more regular interaction with data, and the Council of State and Territorial Epidemiologists (CSTE) recommends that all states make CO poisoning reportable in their jurisdiction. However, it would also duplicate existing data reporting mechanisms and require substantial state and local resources.[23]

[21] Assessing Changes in the Reliability of the U.S. Electric Power System, Lawrence Berkeley Lab (2015)

[22] Some suggestions from CO Safety Coalition, 2023 presentation.

[23] The Notifiable Conditions Rule, Chapter 246-101 WAC, was revised and the rule changes went into effect in January 2023. Notifiable Conditions Rule Revision Implementation (Washington DOH). See additional information in Appendix C: A Note about Notifiable and Provisional Conditions.

Identified Datasets and Tracking Mechanisms

A brief description of the identified and analyzed CO exposure datasets, including those with active tracking mechanisms (in bold), are below. The analysis focused on all unintentional, non-fire related CO exposures in available datasets, including exposures inside and outside the home. See Appendix A: CO Exposure Datasets, Tracking, and Attributed Sources for descriptions of data, limitations, availability, and tracking.

Mortalities

Death certificate data are collected into the Washington DOH Center for Health Statistics (CHS) Cause of Death Literals dataset (2003–2022 and 2023 data analyzed), which includes descriptions of cause, injury, and location. Death certificate data are further tabulated into the Washington DOH Community Health Assessment Tool (CHAT) database (2016-2020; includes intentional and fire-related exposures) and **Washington DOH's Washington Tracking Network (WTN)** database (2000–2022, five-year averages). Incident counts are reviewed as they are prepared for posting to the data portal. This process has spurred awareness, including after the December 2006 Puget Sound windstorm.[24] Those death records that are work-related are reviewed, along with other data sources, by **L&I's Washington Fatality Assessment and Control Evaluation (FACE) Program** (1998–2023), to identify and characterize fatalities. At the national level, the **U.S. Consumer Product Safety Commission (CPSC) National Injury Information Clearinghouse** (2012–2022; includes intentional and fire-related exposures) uses its data in reports, including an annual report on CO poisoning deaths associated with consumer products, awareness campaigns, voluntary standards, rules, and compliance/enforcement efforts. The National Center for Disease Control and Prevention (CDC) National Environmental Public Health Tracking Network (NEPHTN) gathers state CO exposure mortality data (2004–2021, five-year averages).[25] CDC separately published a report in 2023 across multiple federal CO exposure datasets.[26]

Hospitalizations and Hyperbaric Treatments

Hospitalizations, hyperbaric treatments, and mortalities represent the greatest health effects. **Washington DOH's WTN** counts hospitalizations due to CO poisoning (2000–2021, five-year averages) as the data are prepared for posting to the public portal. Virginia Mason Medical Center Section of Hyperbaric Medicine collects data on hyperbaric chamber treatments for CO poisoning, including cause and demographic data (2013–2023; includes intentional and fire-related exposures), and the Washington DOH CHAT Program collects data on hospitalizations with some demographic data (2016–2020; includes intentional and fire-related exposures), but these

[25] December 14-15, 2006 Windstorm (The Storm King, University of Washington)

[26] Source: Conversation with staff from the Division of Environmental Health Science and Practice, National Center for Environmental Health, CDC. Also see updated tracking webpage with data from hospitalizations, emergency department visits, and mortalities: CO Poisoning - Tracking Program, CDC.

[26] Shin, M., *et al.* (2023). *Annals Emerg Med, 81*(3), 309-17. doi: 10.1016/j.annemergmed.2022.10.011.

programs currently do not have specific review processes for the data. The Washington DOH Comprehensive Hospital Abstract Reporting System (CHARS) collects hospitalization data with detailed exposure and patient information but does not have a data review process for CO poisonings (note that CHARS data were not reviewed for this report). The CDC NEPHTN hospitalizations dataset (2000–2021) is collected from some states, including Washington,[25] and the CDC's separately published 2023 report discusses hospitalizations.[26]

Emergency Department Visits

All non-federal emergency department (ED) visits are reported to the Washington DOH **Rapid Health Information NetwOrk (RHINO) Program** (May 2020–May 2023). During a cold snap or upon request, the RHINO program will review visits possibly related to CO poisoning and may share reports with stakeholders if there are statistically more visits than expected.

Poison Center Calls

the **Washington Poison Center (WAPC)** documents calls due to CO poisoning (2013 - 2023 data analyzed), and call center staff would likely notice a rise in CO exposures. WAPC data are sent to the national level and monitored for areas of concern.

Workplace Fatalities and Injuries

Multiple programs at L&I review workplace fatalities and injuries due to CO poisoning. **L&I's Washington (FACE) Program** reviews a variety of datasets with the goal of identifying, characterizing, and generating public-facing reports about fatalities (1998–2023 data available). The **L&I Safety and Health Assessment and Research for Prevention (SHARP) toxic inhalation surveillance system** describes exposures as reported through L&I's State Fund workers' compensation system, which covers ~75 of Washington workers, identifies clusters of related exposures, and provides detailed data tables by industry and occupation. The program also publishes data reports, such as that generated for the SHB 1779 23-24 work group[27] (2017–2022 data). The **L&I Division of Occupational Safety and Health (DOSH) inspection, compliance, and referral investigations** (2007–2020 data analyzed) document and resolve reported CO exposures and concerns; the DOSH investigation data are also reviewed by the L&I FACE program.

[27] Occupational toxic inhalation of carbon monoxide among Washington workers, 2017 – 2022 (L&I, PDF)

Trends in CO Poisonings

In Washington State

Figure 1 shows Rates of CO poisoning mortalities in Washington state.

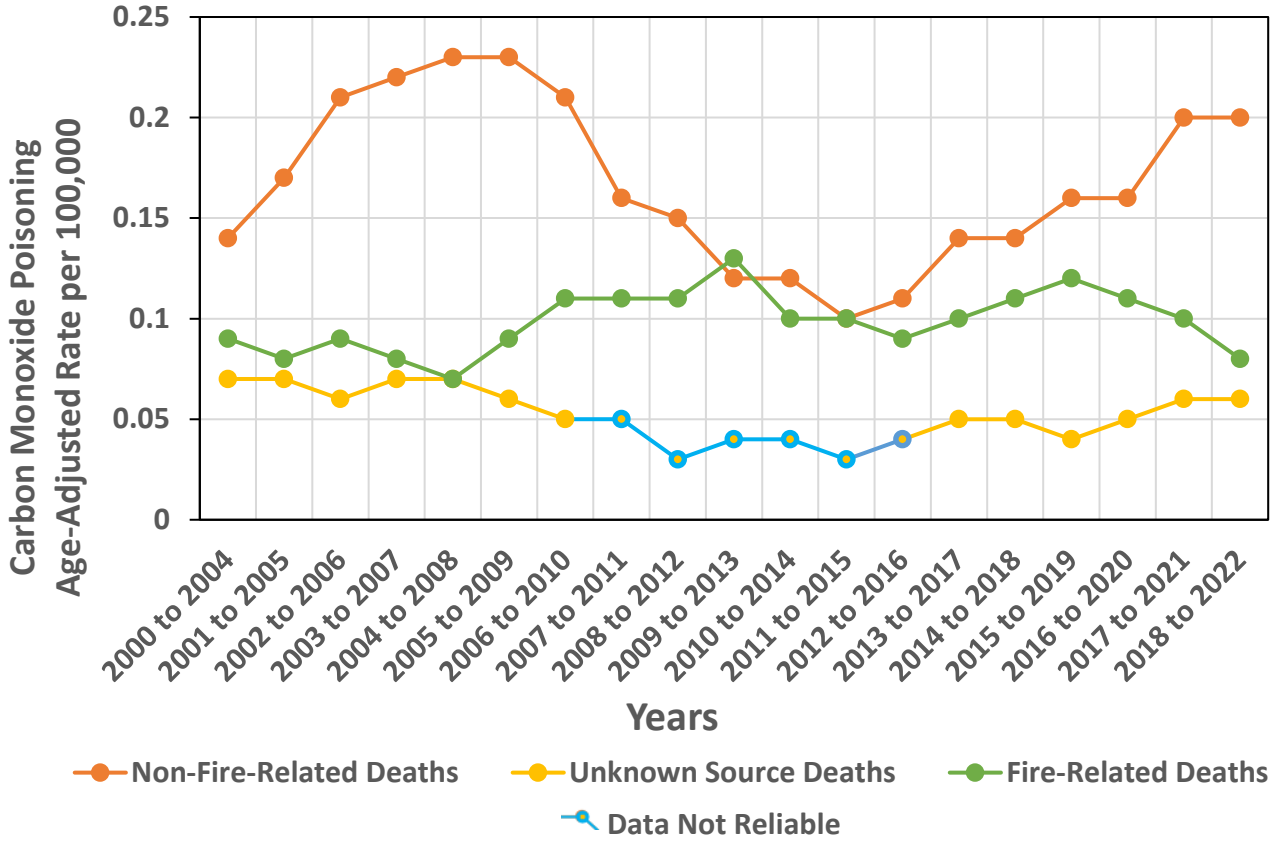

Figure 1. Rates of Washington resident mortalities caused by CO exposure, age-adjusted per 100,000 people (Source: WTN).[28]

The WTN-reported rates of non-fire related, unintentional CO deaths visually rose near the year 2006, when a strong wind event reportedly resulted in eight deaths.[24] The rates of deaths declined afterward, perhaps because of 2009 Washington state legislative actions to require CO detection systems in the state building codes and related awareness (implemented by 2011 and 2013; see Identified Datasets and Tracking Mechanisms).

CO exposure mortality rates visually increased again between the mid-2010s and early 2020s. This trend was also observed in an analysis of unintentional deaths across the U.S. and was attributed

[28] Note: Trends in CO poisoning mortalities are difficult to ascertain due to small numbers. Numbers below 10 are not shown in this report to protect confidentiality and are often aggregated over multiple years. Aggregating over multiple years can have the effect of emphasizing single events. Intentional incidents not included. See Appendix A: Washington CO Exposure Datasets, Tracking, and Attributed Sources for more information.

broadly to consumer product use. Examples of attributable consumer products include portable heaters and generators.[7] Based on datasets with exposure cause data for Washington, the increase in CO exposure mortality rates between the mid-2010s and early 2020s broadly seems to be from a variety of causes rather than one main cause. Notably, climate change has increased the frequency and duration of power outages due to weather events,[29] which may, in turn, increase the use of some CO-generating equipment (such as portable generators and heaters).

Unlike mortality data, trends in CO hospitalizations and other types of incidents have greater interannual variability, and no clear or remarkable trends are observable in the past 10 to 20 years (see Appendix A: CO Exposure Datasets, Tracking, and Attributed Sources).

A Brief Contrast with Other States

Washington state had the 19th highest rate of accidental CO poisoning deaths in 2015–2021, with a crude rate of 0.18 deaths per 100,000, or total of 93 deaths.[6,30] The visible increase after the mid-2010s in Washington state CO exposure death rates can also be seen in data from some other states, including Oregon, California, and Alaska (CDC NEPHTN five-year-aggregated, age-adjusted rates).

[29] Assessing Changes in the Reliability of the U.S. Electric Power System, Lawrence Berkeley Lab (2015)

[30] The crude mortality rate is the mortality rate from all causes of death for a population, not limited or adjusted to particular cause or demographic subset Principles of Epidemiology, CDC.

Causes of CO Poisonings and Prevention Activities in Washington State

Summary

Four main causes of unintentional, non-fire related CO poisonings in Washington were identified, based on analyses of CO exposure datasets.[31]

Motor Vehicles and Gas or Diesel Engines

While improvements to motor vehicle engines have contributed to improved outdoor CO concentrations and declines in CO-related mortality,[32] there are still exposures in the datasets explored in this study that are attributed to combustion engines.

In fact, exhaust from motor vehicle and gas/diesel engines was the first or second most commonly identified cause for CO exposure incidents in all datasets. This could be in the form of exhaust emissions entering a vehicle through holes, such as through the exhaust manifold during vehicle idling, or exhaust emissions entrained or captured in an enclosed or semi-enclosed space such as a garage or loading dock.

CO-Related Incidents Attributed to Motor Vehicles and Gas or Diesel Engines

24% of CO product-related mortality incidents (includes intentional, fire-related)
40% of CO deaths in death certificates 2003–2022; **55%** in 2023
22% of CO hyperbaric treatments (includes intentional, fire-related)
39% of CO hospitalization cases (includes intentional, fire-related)
11% of CO ED visits
16% of CO poison center calls *with known cause* and at least minor effects
20% of workplace inspections where CO was measured
43% of CO workplace exposure claims

[31] Exposures were limited to those attributed to unintentional and/or non-fire related causes, unless indicated. Unspecified/unknown source cases are included in percentages unless indicated. Organizations determined cause of exposure cause prior to sending data or work group members using information provided such as diagnosis codes. See Appendix A: CO Exposure Datasets, Tracking, and Attributed Sources. Exposures inside and outside the home were considered.

[32] Mott *et al.* (2002) National vehicle emissions policies and practices and declining US carbon monoxide-related mortality. *J Amer Med Assoc, 288*(8), 988-995. doi:10.1001/jama.288.8.988.

What's Already Being Done

See important details in the full list of Ongoing Prevention Activities: Motor vehicles and gas/diesel engines.

- There is limited guidance around low-level CO personal exposure monitors, which can be used where potential sources of CO exist.
- The Washington state building code requires protections like CO detection systems and specified ventilation rates in some indoor spaces; protections could be improved in spaces such as garages, sheds, and loading docks.
  - The standard required for CO alarms was updated to include recreational vehicles (RVs), commercial vehicles, and unconditioned spaces.
- Law enforcement and government vehicle fleets have addressed exposures through fleet CO sensor deployment, repairs, and hybrid/electric vehicle adoption. Investigations were made into the cause of officer exposures in patrol vehicles. In addition, U.S. employers must ensure a commercial motor vehicle is not used when CO is detected (49 CFR 392.66).
- L&I enforces safety standards in Washington state workplaces.
- Programs to incentivize electric vehicles and charging infrastructure are ongoing. While the intent of this programming is to prevent greenhouse gas emissions, reduced or eliminated CO emissions and other harmful pollutants are a co-benefit.
- Specific messaging is available from several resources (see the full list of Ongoing Prevention Activities: Motor Vehicles and Gas or Diesel Engines).

Fuel-Powered Heating and Cooking Devices, including Wood but Not Gas Stoves

Exhaust from fuel-powered heating and cooking devices was a leading cause of CO exposure-related mortalities, hospitalizations, and poison center calls. As demonstrated through ED visits, device examples include propane, kerosene, or other heaters (34% of visits); wood fireplaces and stoves (15%); other heaters (15%), charcoal briquettes, barbecues, and grills (14%); and other propane devices (14%). Gas stoves and ovens were considered appliances. Many of these exposures occurred in temporary dwellings: 45% of CO deaths associated with these devices were in a trailer, camper, motor home, RV, vehicle, tent, truck, or van.[22]

CO-Related Incidents Attributed to Exhaust from Fuel-Powered Heating and Cooking Devices

33% of CO product-related mortality incidents (includes intentional, fire-related)
24% of CO deaths in death certificates 2003–2022
8% of CO hyperbaric treatments (includes intentional, fire-related)
8% of CO ED visits
9% of CO poison center calls *with known cause* and at least minor effects
<10% of workplace investigations where CO was measured

What's Already Being Done

See important details in the full list of Ongoing Prevention Activities: Fuel-powered heating and cooking devices (including wood but not methane gas stoves).

- Charcoal briquette packages are federally required to have **CO hazard labels**.

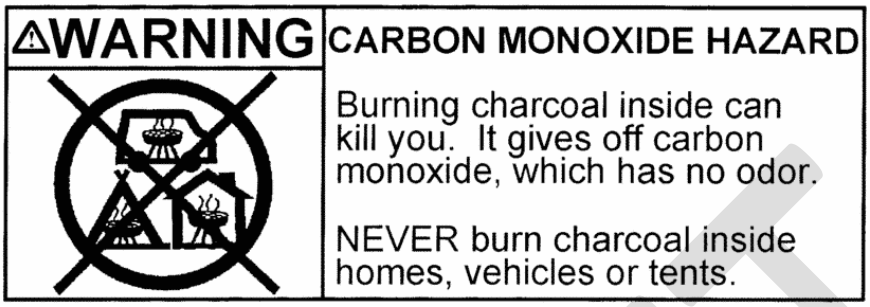

Figure 2. Labeling required for charcoal briquettes (U.S. CPSC).

- ECY's Wood Smoke Reduction Grant Program helps people scrap or recycle old wood stoves that are inefficient and highly polluting and replace them with more efficient, less polluting devices.
- There is limited guidance around low-level CO personal exposure monitors, which can be used where potential sources of CO exist.
- A voluntary standard requires CO alarms in some RVs.
- Limited specific messaging is available (see the full list of Ongoing Prevention Activities: Fuel-powered heating and cooking devices).

Fuel-Powered Tools and Equipment, including Generators

Fuel-powered tools and equipment, including generators, accounted for a large portion of reported Washington CO exposures, especially in the workplace. Engine-driven tools caused the largest percentage of deadly unintentional, non-fire CO poisoning incidents associated with U.S. CPSC consumer products (2020 data; 166 incidents and 211 deaths).[7]

Generators accounted for about half of all the deaths associated with consumer products, and 92 of the 101 estimated engine-driven tool-associated deaths. According to U.S. CPSC, one portable generator produces as much CO as hundreds of cars.[33]

[33] Generators and Engine-Driven Tools (CPSC)

CO-Related Incidents Attributed to Fuel-Powered Tools and Equipment, including Generators

- **14%** of CO-related mortality incidents *due to generators* (includes intentional, fire-related)
- **13%** of CO deaths in death certificates 2003–2022
- **15%** of CO hyperbaric treatments *due to generators* (includes intentional, fire-related)
- **10%** of CO ED visits
- **8%** of CO poison center calls *with known cause* and at least minor effects
- **44%** of workplace inspections where CO was measured
- **2 of 3** total workplace fatalities caused by CO

Types of Tools and Equipment

Of the ED visits attributed to fuel powered tools and equipment, the most frequently identified source tools were (in order of prevalence): generators, pressure washers, concrete saws, other saws, concrete mixers, lawn mowers, carpet steamers, skid steer loaders, air compressors, and unspecified tools/machines/motors. Generators were more prevalent than all other tools.

Of workplace compliance inspections where CO was measured, the most frequently identified source tools and equipment were fuel-powered forklifts or manlifts (often warehouse/industrial) (22%), fuel-powered floor equipment (cleaning, buffing, etc.) (12%), other/multiple fuel-powered pieces of equipment (<10%), fuel-powered generators (<10%), and fuel-powered pressure washers (<10%).

What's Already Being Done

See important details in the full list of Ongoing Prevention Activities: Fuel-Powered Tools and Equipment, including Generators.

- Danger labels on generators are federally required.
- Specific messaging is available from multiple sources on generator safety, product recalls, and propane forklift and other power tool CO poisoning prevention (see the full list of Ongoing Prevention Activities: Fuel-Powered Tools and Equipment, including Generators).
- A proposed rule would require sensors and automatic shut-off features on portable generators.
- L&I enforces safety standards in Washington state workplaces.
- Legislation has been introduced in recent years toward adopting zero-emission small off-road engines and equipment standards.

Fuel-Powered Appliance Malfunctions

Exhaust from malfunctioning fuel-powered appliances, including gas stoves, caused some CO exposure-related incidents in Washington, especially in the workplace and amongst patients who subsequently received hyperbaric treatments.

Nationally, a report from the U.S. CPSC found that heating systems caused the second largest percentage of non-fire CO poisoning deaths associated with the use of consumer products under U.S. CPSC's jurisdiction.[7]

While building CO alarms have been required in Washington for more than a decade in institutional and residential spaces (and more recently educational spaces), CO exposures still occur due to appliances that are not working properly. These appliances include furnaces, water heaters, commercial/gas stoves, laundry machines, and radiators (Virginia Mason Hyperbaric Chamber and WAPC data). While most exposures from appliances occur within the home (about 2,500 of 3,200 calls to the WAPC about CO concerns occurred in a residence), exposures outside the home at workplace or commercial locations also occur.

CO-Related Incidents Attributed to Fuel-Powered Appliance Malfunctions

- **<12%** of CO-related mortality incidents (includes intentional, fire-related)
- **<2%** of CO deaths 2003–2022
- **24%** of CO hyperbaric chamber treatments (includes intentional, fire-related)
- **6%** of CO ED visits
- **8%** of CO poison center calls *with known cause* and at least minor effects
- **<10%** of workplace inspections where CO was measured

A Note about CO Alarms and Chronic, Low-Level Exposures

The December 2023 death of an Evergreen State College student[34] reminds Washington that there is still a need for awareness and education about CO alarms. In addition, there is a need for more accessible measurements of CO at low levels to avoid chronic exposures. Of approximately 2,500 calls made to the WAPC about CO poisoning concern in a residence, about 550 were chronic or acute-on-chronic exposures. Current CO alarm designs[13] do not *allow or require* the alarm to warn a user of CO concentrations that could cause chronic effects. When alarms repeatedly sound, they may be turned off. Additional work is needed to address measurements for these low-level exposures.

[34] Findings – Evergreen State College Carbon Monoxide Death Investigation - WSP

What's Already Being Done

See important details in the full list of Ongoing Prevention Activities: Fuel-Powered Appliance Malfunctions.

- Incentive programs to choose electric appliances are available.
- Recent building code and policy proposals have supported the transition to electric appliances.
- The state adoptions of the building codes require CO alarm or detection systems, including within non-residential structures, such as schools and workplaces.
- Washington DOH and L&I inspect temporary worker housing for issues including working CO alarms.
- A proposed rule would require safety features on residential gas furnaces and boilers.
- Research and discussions are ongoing about lowering CO alarm thresholds.
- Specific messaging is available from several sources on product recalls, appliance installation and inspections, and electrification strategies (see the full list of Ongoing Prevention Activities: Fuel-Powered Appliance Malfunctions).

Other Factors - Intentional CO Poisonings

While intentional CO poisonings were not the focus of this work group's analysis, intentional CO poisoning deaths occur in Washington state every year. Since the 1970s, intentional CO deaths have been declining, in part due to improved motor vehicle emissions[6,32]. In 2015–2021, there were nearly twice as many deaths due to intentional CO poisoning in Washington state (161) than unintentional (93),[6] although trends suggest that may be changing.[7]

What's Already Being Done

- Washington uses the easy-to-remember three-digit phone number 988 to reach the National Suicide Prevention Lifeline[35]. The line can be accessed by call or chat, and translators are available.
- Washington DOH provides resources to get help and keep loved ones safe at Suicide Prevention - In Crisis (Washington DOH).

[35] 988 Suicide and Crisis Lifeline Launches (Washington DOH)

Other Factors - Storms

In several CO exposure datasets, clusters of cases were observed near storm events, when newspaper articles reported winds and power outages. For example, in November 2015, a windstorm left many without power.[36] A rise in CO exposure cases in the Virginia Mason Hyperbaric Chamber and Washington Poison Center datasets were visible during this time, with sources including generators, motor vehicle exhaust, furnaces, water heaters, and charcoal.

What's Already Being Done

See important details in the full list of Ongoing Prevention Activities: Other Factors – Storms.

- Some programs perform regular review of CO exposure datasets and have successfully identified past events. However, no review across datasets is done for CO.[37]
- Some messaging is disseminated prior to major storms/stormier seasons. More local messaging could improve prevention activities.

Other Factors – Firefighter Smoke Inhalation

Datasets included in this report show only two clearly documented instances of firefighter overexposure to CO: an exposure to vehicle emissions within a firehouse (DOSH workplace inspection) and an exposure of one firefighter involved in a structural fire (ED visit). The 2017–2022 L&I Toxic Inhalation Surveillance report also showed that the industry sector including firefighters, Public Administration, had the highest number of CO exposure cases. Some datasets also did not have sufficient detail to identify exposure of a firefighter. While the focus of this report was not fire-related exposures, it will briefly discuss firefighters' exposures.

What's Already Being Done

See important details in the full list of Ongoing Prevention Activities: Other Factors – Firefighter Smoke Inhalation.

- Appropriate personal protective equipment are required for fire department members.
- Existing systems for firefighters to document and report exposures have been evaluated; these systems remain voluntary.
- Monitoring equipment for CO and other pollutants near wildfires can be borrowed through a pilot project to support ongoing research.

[36] 2 killed, thousands without power as winds hit Washington state (The Seattle Times)

[37] See CO Exposure Datasets and Tracking in Washington

Other Factors – Boats and Boat Engines

Exposures on boats or ships accounted for 3% and boat engine exhaust exposures accounted for <2% of CO ED visits, exposures from boat exhaust accounted for <3% of CO poison center calls *with known cause* and at least minor effects, and <6% of CO hyperbaric treatments.

What's Already Being Done

Any new or used motor-driven boat or vessel sold in Washington must display a CO warning sticker developed or approved by the Washington State Department of Licensing and the U.S. Coast Guard. See Appendix B: Building Codes, CO Alarm and Detection Requirements.

Locations and Seasons of Exposures

Many CO exposure incidents were observed to occur at home. Vehicles and temporary dwellings, shops and sheds, and workplaces were other common locations. For example:

- 36% of ED visits were in the patient's home. Other locations:
  - Workplaces (**14%** of known locations)
  - In vehicles (**13%**)
  - Dwellings other than or not specified as the patient's home (**10%**)
  - Temporary dwellings including trailers, campers, tents, and RVs (**9%**)
  - Garages, shops, and sheds (**8%**)
  - Boats and ships (**6%**)[38]
- Among Washington DOH Cause of Death Literals:
  - **27%** occurred in a garage, home with attached garage, carport, shop, shed, or shack
  - **27%** occurred in a trailer, camper, motor home, RV, vehicle, tent, trucks or van
  - **24%** occurred in a house, apartment, townhouse, mobile home, or home.

While the majority of CO exposure incidents are consistently reported in colder months (this is well documented[2,7] and was observed in multiple datasets by the work group), incidents still occurred in the warmer months. Among ED visits, 18% of CO exposure visits occurred in April through June, and 21% were in July through September (2021–2022 data).

While the causes of visits between seasons were mostly similar, generators and gas leaks were more common causes of CO exposures in the colder months than in warmer months. In the warmer months, the only uniquely common cause of exposure was diesel exhaust from an unspecified non-motor vehicle source, with all visits attributable to a single incident involving a diesel engine aboard a marine vessel.[39]

[38] Note that at least 15 ED visits categorized as occurring at a boat/ship location were from the same incident.

[39] Sailors taken to hospital for diesel exhaust exposure at shipyard (Kitsap Sun) July 2021

At-Risk Populations for CO Poisonings in Washington

Overview

At-risk populations identified for CO poisonings in Washington include those who possess characteristics of groups with higher observed rates of exposures or who are at greater risk of CO poisoning. The work group found that further information is needed to point to specific occupations, activities, or groups that could be the focus of prevention messaging.

Groups with higher observed rates of CO poisonings are people who are:

- Middle-aged
- Male (sex)
- Identifying as "Other Race"
- Working in occupations that require the use of, or proximity to, fuel-burning devices
- In temporary dwellings such as trailers, campers, motor homes, RVs, vehicles, tents, trucks, or vans (such as people who are unhoused)

Groups who are at greater risk of CO poisonings are people who are:

- Sleeping, using alcohol, or using other substances
- Physically exercising
- Experiencing external heat and/or overly warm clothing
- Experiencing anxiety due to emotional or psychological conditions
- Have an underlying health condition
- Are pregnant or under the age of 5

Age

People who are middle-aged are *more frequently exposed and poisoned* by CO exposure.

- **Hospitalizations:** Most nonfatal CO poisonings were among people of middle age (55.6% of exposures were in people 45 to 69 years old).
- **ED visits:** Numbers of visits of people 18 and over were disproportionately high (84% versus 79% of population in 2022[40], *p*=0.001).
- **Workers:** Among workers, the median age of non-fatal CO exposures reported 2017–2022 was 38 (12 were under age 20, 13 were older than age 64; out of 507 cases).[27]

[40] Based on the U.S. Census ACS Demographic and Housing Estimates. Note: The comparison of these datasets is inherently uncertain because the datasets differ in that they represent visits (RHINO) and individuals (U.S. Census).

- **Hyperbaric treatments:** People aged 40 to 49 accounted for most CO poisoning cases.[41]
- **Deaths:** Death certificate data revealed that people aged 45 to 64 years accounted for the greatest number of CO poisoning cases. The greatest number of deaths worldwide due to CO poisoning 2000 to 2021 was in the 50 to 54 year age group.[42]

Children and the elderly are *at greater risk* of CO poisoning.

- People under age 5 have the most years of life lost due to mortality internationally.[42]
- The California Air Resources Board finds that unborn babies, infants, and elderly people are most likely to experience health effects with exposure to elevated levels of CO.

Sex

Available datasets showed modestly greater numbers of CO exposures in males for the general population and workers in Washington.

Hospitalizations: Washington hospital discharge data demonstrated a higher percentage of males with CO exposure diagnoses: 64% of exposure cases were about males; 36% were about females (CHAT, 2016–2020, includes intentional, fire-related, and unspecified source exposures).

ED visits: While not statistically significant, numbers of ED visits were slightly lower among females compared to population estimates (2% lower than 2022 U.S. Census American Community Survey, ACS, Demographic and Housing Estimates, p= 0.575). Numbers of ED visits were slightly higher amongst males compared to population estimates (1% higher than 2022 U.S. Census ACS Demographic and Housing Estimates, p=0.561).

Deaths (U.S., global): Nearly 75% of CO poisoning deaths in the U.S. 2015–2021 were among males[6]. Globally, males are much more likely to die of CO poisoning than females, possibly due to workplace exposures or activities such as operating machinery or grilling.[42]

Workers: Among workers, L&I's toxic inhalation surveillance system[43] found that non-fatal CO exposures reported 2017–2022 were for people identified as 68% male (507 cases).

[41] Hampson, N. B.; Dunn, S. L.; Yip, F. Y.; Clower, J. H.; & Weaver, L. K. (2012) *Undersea & Hyperb Med Soc*, *39*(2), 667-685. https://pubmed.ncbi.nlm.nih.gov/22530450/

[42] GBD 2021 Carbon Monoxide Poisoning Collaborators (2023) *Lancet Public Health 8*(11), e839-49, https://doi.org/10.1016/S2468-2667(23)00185-8

[43] Toxic inhalation surveillance system report prepared for the work group: Occupational toxic inhalation of carbon monoxide among Washington workers, 2017 – 2022.

Race, Ethnicity, and Spoken Language

ED visits: Disproportionately high numbers of ED visits were observed among people designated as "Other Race" (p=0.002), compared to the population.[40] No additional information was available to identify disproportionately impacted people designated as "Other Race." The numbers of visits were also high, but not statistically significant (p>0.05) among people designated as "Black or African American" and "White". "Hispanic or Latino" people in Washington were not statistically significantly impacted.

Workers: L&I's SHARP Program identified in 2017–2022 workers compensation claims that "the preferred language for the claim process was English in 93% of cases, Spanish in 6% of cases, and all other languages in 1% of cases".[27]

Behavior

People who are sleeping, using alcohol, or using other substances are at greater risk because CO cannot be sensed, and a person can lose consciousness and become unaware of symptoms.[6]

People in temporary dwellings such as trailers, campers, motor homes, RVs, vehicles, tents, trucks, or vans (such as people who are unhoused) are more often exposed.[44]

Factors that may put people at greater risk of CO poisoning upon exposure also include:[1]

- Being physically active, since physical exercise increases pulmonary ventilation, the rate of carboxyhemoglobin formation is also increased, and hypoxia is also exacerbated due to increased oxygen metabolism.
- An increase in body temperature from external heat or clothing could increase the effect of CO exposure.
- Emotional or psychological conditions causing anxiety that increase pulmonary ventilation.

Underlying Health Concerns and Conditions

Some underlying health conditions may cause people to be at greater risk of CO poisoning. Studies and reports highlight specific conditions[1,3,4] including cardiovascular disease, coronary artery disease, congestive heart failure, potential stroke, a history of heart or respiratory disease, or anemia. People who are pregnant are also at greater risk because they can have higher carboxyhemoglobin levels; fetuses are at greater risk because their blood hemoglobin affinity for CO is greater than that for adults.

[44] See data summaries under Fuel-powered heating and cooking devices (including wood, but not gas stoves) and Locations and Seasons of Exposures.

Work Group Recommendations

The work group recommends the following current and future state agency activities, policy options, and other actions to reduce CO poisoning in Washington:

(a) Prevent CO poisoning from sources outside of the home: Washington agencies, in collaboration with the University of Washington Department of Environmental and Occupational Health Sciences, should study the measurement capability and utility of portable CO monitors.

Portable CO monitors could reduce exposures by alerting individuals with displays or alarms in spaces where CO alarms don't exist, and at lower CO concentrations than those at which typical building alarms alert. Researchers at the University of Washington have expressed interest in collaboration. The study should focus on:

- How well CO monitors detect harmful concentrations and device aspects necessary for successful deployment, use, and maintenance.
- Whether there are incentives or subsidies for portable CO monitors available.
- Environments where CO monitors can be used to prevent exposures and best practices for monitoring in those spaces. This would include devices for:
  - Personal use (placed near the breathing zone on the lapel, for example).
  - Use in vehicles or motor homes to alert when exhaust is leaked into or entrained inside the vehicle. Vehicles may be for law enforcement, commercial, or public use.

The goal of the study is to provide guidance for Washington residents about how to select and use a portable CO monitor.

(b) Increase awareness of CO among the most at-risk populations: DOH should build a CO exposure prevention toolkit for community-based organizations and local health partners.

The toolkit can build on CPSC CO Safety Toolkit and work from other states. The material should be translated into multiple languages and disseminated to community-based organizations throughout Washington to include people who are at risk.

Messages Should Cover:

- Fuel-powered tool and equipment safety and electric alternatives, including forklifts and manlifts, generators, power washers, floor cleaning equipment, and saws.
- Protections such as ventilation and following device warning labels for garages and sheds.
- State building code requirements for enclosed loading dock airflow rates and alarms.
- Fuel-powered cooking and heating device safety with focuses on:
  - The need for sufficient ventilation.
  - Temporary dwellings such as truck cabs, vans, RVs, tents, cars, and other shelters used by people who are unhoused.
  - Congregate settings.
- Ongoing maintenance of CO alarms and detection systems.
- Resources available, such as the 988 Suicide and Crisis Lifeline that can help prevent intentional CO poisoning.

(c) Collect data on the number of incidents of CO poisoning and their causes in Washington, and to track the reduction of incidents over time: Washington state would benefit from bringing together an ongoing committee of state agencies and organizations to review data and develop timely messaging.

The work group recommends a committee consisting of agencies and organizations involved in CO exposure data collection. The main committee focus would be to conduct periodic review of CO exposure data to identify trends in CO exposure numbers, causes, and vulnerable at-risk groups. The committee could also study causes of the observed increase in deaths associated with CO exposures.[6,7]

Using their findings, committee members should engage in joint messaging and press release campaigns in autumn when exposure numbers typically start to increase and following CO exposure events or clusters. Timely messaging would make communication and outreach more proactive, frequent, and collaborative, with an emphasis on prevention.

Committee members might include Washington DOH programs (WTN, RHINO, CHARS, and CHS Vital Statistics), Washington L&I SHARP and FACE, WAPC, and the Virginia Mason Medical Center. Programs collecting relevant data could provide a summary of recent data.

Unintentional as well as intentional CO poisonings should be included in the work.

(d) Funding opportunities available for public awareness campaigns related to CO harm avoidance: The work group found limited resources available to raise awareness on CO harm avoidance outside the home.

- Funding is available for some CO building alarm installation and development of training and education, including from U.S. CPSC and a Johns Hopkins project.[45,46]
- Grant funding is also provided for CO research topics such as improving detection where exposure risk cannot be eliminated. This is available through the CO Research Trust, a United Kingdom nonprofit organization.[47]

Further work group recommendations on new policy options and other actions that could be taken to reduce CO poisoning: Washington state has the ability to take stronger positions in support of policy and legislative decisions that would result in health co-benefits.

The health co-benefit of eliminating CO emission sources should be elevated when legislative and policy decisions are made about electrification for vehicles, portable heating and cooking devices, tools and equipment, and appliances, as well as anti-idling work.

This may include:

- *Supporting electric vehicle and charging infrastructure programs* such as the 2023 Electric Vehicle Council Transportation Electrification Strategy (TES), programming to build and support charging infrastructure, and Ecology's Zero Emission School Bus Grant Program (PDF), which includes maintenance training programs.

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[45] The Carbon Monoxide Poisoning Prevention Grant Program (COPPGP) (U.S. CPSC) funds state, local, and tribal governments to purchase and install CO alarms in residences and facilities serving low-income families, elderly people, or children; and to develop training and education. This grant is anticipated to repeat in future fiscal years, pending funding. In 2024, Central Pierce Fire & Rescue received this award. Their organization will spread awareness about the dangers of CO poisoning and benefits of installing CO alarms, particularly focusing on low-income families and vulnerable populations. Their outreach will include a presence at the Washington State Fair, social media and billboard campaigns about requesting alarm installations, and group-specific education programs at schools and with seniors. Additionally, they are working on education for the community through partnerships with groups such as other emergency service providers, local government entities, local food banks, and homeowners' associations. Resources will be available at their Fire & Life Safety Page For All (Central Pierce Fire & Rescue), K-12 Safety Education Page (Central Pierce Fire & Rescue), or Carbon Monoxide Safety Page (coming soon).

[46] The Johns Hopkins Smoke Alarm Project is funded by FEMA to supply free smoke and CO alarms to tribal partners, along with educational and training materials. Johns Hopkins ships the alarms and materials to tribal partner locations across the country, and partners then help to get the devices installed within their tribal community.

[47] CO Research Funding (NCOAA)

- *Supporting decisions to incentivize electric tools and off-road equipment*, including forklifts and manlifts, generators, power washers, floor cleaning equipment, saws, and landscaping or yard equipment.
- *Supporting incentive programs to choose electric appliances* through messaging and continued funding, such as the Washington State Department of Commerce Home Electrification and Appliance Rebate (HEAR) Program and the EPA Climate Pollution Reduction Grant funding for vehicle electrification and for zero emission appliances.
- *Supporting or extending opportunities for anti-idling work*, such as ECY's Clean Diesel Grant Program.

Washington state should make public statements in support of proposed U.S. CPSC Safety Standards on Portable Generators and Residential Gas Furnaces and Boilers.

Conclusion

While the work group identified main causes of unintentional CO exposures in Washington using current datasets, more work is needed. Unintentional CO poisonings are preventable, and the death rate has risen between the 2010s and 2020s in Washington. The cause of this increase is not yet clear.[5,6] Specific at-risk groups to reach through prevention messaging are still unclear. More information is needed to understand disproportionately impacted groups, such as people identified as "Other Race" and people in temporary dwellings (who may or may not be unhoused).

The work group consensus is that more opportunities exist to further understand and prevent CO exposures in Washington. The state should support legislative and policy decisions that remove CO sources from enclosed spaces, improve messaging, and improve understanding of monitors for low-level detection and spaces with no required CO alarms.

Appendix A: CO Exposure Datasets, Tracking, and Attributed Sources

About the Data and Analysis

Datasets were evaluated for incidents with suspected, probable, or confirmed CO poisoning, roughly based on the CDC surveillance case definition.[48] Percentages of cases listed below are calculated out of all cases with *identifiable* causes, unless "unknown" or "unspecified" categories are listed. Datasets include only unintentional, non-fire related data unless specified. Small numbers of incidents/visits (9-10 or fewer) are suppressed. Analyses of most datasets were performed manually (including the association with location, cause, etc.).

Seasons in which Exposures Occur in Washington

- Hyperbaric chamber treatments occurred mostly in **colder months**: 40% in December through February; 29% in September through November; 19% in March through May; and 1% in June through August.
- ED visit numbers were slightly higher in colder months but were **still observed in warmer months** (18% in April through June; 21% in July through September; 2021 and 2022 data).
- **Storms** in December 2006 and November 2015 were evident in numbers of poison center calls and hyperbaric chamber treatments.

Mortality Datasets

CDC NEPHTN – Mortalities

Data Collected

Age-adjusted mortality rates per 100,000 people from death certificates were collected for 2004-2021 (five-year averages), as reported by states to the National Center for Health Statistics (NCHS).

[48] Carbon Monoxide Poisoning 2019 Case Definition | CDC

Data Limitations

No exposure cause information was included. Differences between states are possible due to variations in death investigation laws, the classification of deaths into intentional and unintentional, and unrecognized CO poisonings. See Washington DOH WTN – Mortalities.

Data Availability

Data were available publicly from the CDC NEPHTN data explorer.

Tracking and Reporting Mechanism

The CDC has federally designated CO poisoning as a notifiable condition.[48] To provide baseline data for the new CO poisoning case surveillance, CDC published a report in 2023 across multiple federal level CO exposure datasets.[26] Some CO exposure and prevention research is also being done at CDC NIOSH.

Attributed Exposure Sources (CDC NEPHTN – Mortalities, 2004-2021)

No data showing source of CO are available in this dataset.

Washington DOH CHS – Cause of Death Literals

Data Collected

Data include death certificates for Washington residents including out of state and non-resident deaths that occurred in Washington, from 2003-2022 and 2023. Cause of death is based on the underlying cause of death determined by the medical practitioner or examiner. The dataset included immediate and underlying causes, injury description, and injury place.

2003-2022 data: All incidents (*n*=1,185,000, approx.) were searched for "immediate" and/or "underlying" cause of death with an exact match of "carbon monoxide". Data were further classified manually as intentional or fire-related. Cases were also manually associated with an exposure cause and scenario. Analysis by a work group member from Washington DOH.

2023 data: All electronic death certificate records from WA residents in 2023 (*n*=65,000, approx.) were searched for "immediate" and/or "underlying" cause of death with an exact match of "carbon monoxide". Data were further classified manually as intentional. Cases were also manually reviewed and associated with an exposure cause and scenario using the 'injury place' and 'how injury occurred' text fields. Analysis by a work group member from L&I.

Data Limitations

Data are entered into death certificates by various professionals and are subject to human error. Determination of intent and whether a death was fire-related, was done manually by a work group member, and the numbers of unintentional and non-fire-related deaths are likely

overestimated. Data are estimated to be 99% complete. NCHS assigns diagnostic codes; Washington DOH CHS performs routine data quality checks.[49]

Data Availability

Data are available via a data sharing agreement with Washington DOH.

Tracking and Reporting Mechanism

Data from death certificates are tabulated into the CHAT and WTN databases, as required by CDC. The WTN team publishes numerical incident data from CHAT to the WTN public portal on the Washington DOH website and sends the data to CDC. L&I uses the dataset to identify and characterize work-related fatality cases, with different programs focusing on different subsets of the data based on cause or conditions.

Attributed Exposure Sources (Washington DOH CHS – Cause of Death Literals)

2023 Data

A total of 31 likely unintentional, non-fire related deaths were identified.

- Exhaust - motor vehicle or other engine (55%)
- Unknown (<30%)
- Charcoal fire (<30%)
- Residential fire (<30%)
- Fuel powered appliance malfunction (<30%)
- Fuel powered heater/cooking (<30%)
- Exhaust – boat (<30%)

55% of deaths were identified as being likely intentional.

Many cases occurred at the victim's residence, and many included positive toxicology results for other substances. No cases were flagged as, or appeared to be, work-exposure related.

2003-2022 Data

A total of 638 likely unintentional, non-fire-related deaths were identified.

- Exhaust - motor vehicle or other engine (40%)
- Fuel powered heater/cooking (24%)
- Unknown (18%)
- Fuel powered generator (10%)
- Fuel powered tools or equipment (3%)
- Fuel powered appliance malfunction (<2%)
- Exhaust – boat (<2%)

[49] See the Data Users Guide on the Death Data (Washington DOH) webpage.

- Vehicle wreck (<2%)

20% of deaths in the dataset were identified as likely intentional, based on description of scene and notes in the documentation. This likely an underestimate.

Washington DOH CHAT - Mortalities

Data Collected

Mortalities with primary diagnostic codes relating to CO poisoning and from 2016-2020 in the CHAT database were included. The CHAT dataset is aggregated from multiple sources: in the CHAT database death certificates, CHARS data, survey data from BRFSS, and other sources.

Data Limitations

Limited cause information (diagnostic code only) was included.

Data Availability

CHAT data are restricted for use by state, local, tribal, and other public health agency staff. CHAT is accessed through a data sharing agreement available through a CHAT coordinator.[50]

Tracking and Reporting Mechanism

While the CHAT program is not aware of all uses of the data, the program is not aware of a process by which the CO exposure data would be regularly reviewed.

Attributed Exposure Sources (Washington DOH CHAT – Mortalities, 2016-2020)

No deaths related to CO poisoning diagnostic codes were identified in this dataset.

Washington DOH WTN – Mortalities

Data Collected

2000-2020 data were included from the WTN database, which are from the CHAT database (and further from DOH CHS), simplified for public use. CO poisoning deaths met the CSTE surveillance case definition for a "confirmed" case in administrative datasets. The dataset differentiates deaths using ICD-10 codes: unintentional; unintentional fire-related; unintentional non-fire-related; and undetermined intent.[51]

[50] Community Health Assessment Tool (Washington DOH)

[51] ICD-10-CM: Classification of Diseases, Functioning, and Disability (CDC)

Data Limitations

No exposure cause information was included. Data were aggregated to five years because of small numbers.

Data Availability

Data are available to anyone through WTN's web portal.

Tracking and Reporting Mechanism

The WTN team looks at the data when they prepare it for the query portal. The last time there was a significant increase in cases was in 2006, when there was a windstorm in the Puget Sound region. At that time, there was a review and an awareness campaign.

Attributed Exposure Sources (Washington DOH WTN – Mortalities, 2000-2020)

No data showing source of CO are available in this dataset (only counts).

CPSC National Injury Information Clearinghouse

Data Collected

Incident data involving consumer products under CPSC jurisdiction from 2012-2022 were included. Data are collected online; through a free consumer hotline; via postal mail; from reports from other federal, state, and local consumer entities; through reports of incidents; and from medical reports.[52]

Data Limitations

Data include exposure cause. Intentional and fire-related cases could not be consistently differentiated. The variety of sources make this dataset less certain and possibly incomplete. Only mortalities were included. There may be multiple deaths per incident.

Data Availability

The data are readily available on the CPSC website: Clearinghouse Online Query Tool (CPSC).

Tracking and Reporting Mechanism

Active tracking and reporting activities for CO exposure prevention by CPSC are substantial.

The CPSC produces reports on the "Annual Estimates of Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products".[53]

[52] Clearinghouse Online Query Tool (CPSC)

[53] Carbon Monoxide Documents and Reports (CPSC)

Clearinghouse CO exposure data are used to inform prevention in the following ways. Please note: the following statement was prepared by CPSC staff. It has not been reviewed or approved by, and may not represent the views of, the CPSC.

1. By raising awareness. This is done first by [the CPSC program of] Epidemiology, which analyzes the data, compiles statistics, identifies emerging hazards, and publishes reports; and second by the Office of Communication, who post the reports online, coordinates with various awareness campaigns, creates flyers with key points, highlights on social media, and coordinates with the press.

2. By working with Standards Development Organizations (SDOs) to develop voluntary standards to address hazards. By statute, before [CPSC] can begin to pursue rulemaking, [they] are required to work to improve or develop voluntary standards to address hazards. [They] do this by collaborating with SDOs, including providing data. Only after [they] make findings that include that a voluntary standard is not likely to adequately reduce the hazard, or the voluntary standard is likely adequate but is not likely to be substantially complied with, can [they] pursue rulemaking.

3. By rulemaking. This is an agency-wide effort with contributions from multiple CPSC components in which [they] analyze data, conduct tests, and so on to determine how [they] can make products safer.

4. Via compliance monitoring and enforcement. Within CPSC, Compliance largely oversees this, such as through assignments of in-depth investigations or data requests to [Epidemiology] for product safety assessments, and so on. That said, CO poisonings, at least from generators and [Engine Driven Tools], are usually not due to a product malfunction, and there are no mandatory standards for CO emissions yet for Compliance to enforce.

Attributed Exposure Sources (CPSC National Injury Information Clearinghouse, 2012-2022)

85 total fatal exposures were found in Washington.

- Fuel powered heater/cooking (33%)
- Exhaust – motor vehicle (20%)
- Unknown (15%)
- Fuel powered generator (14%)
- Fire (<12%)
- Fuel powered appliance malfunction (<12%)
- Exhaust – faulty motor vehicle (< 12%)
- Exhaust – other engine/fuel (< 12%)

Locations of exposures (descending order of frequency): house, apartment, townhouse, mobile home, or home (35%); garage, home with attached garage, or shop (22%); trailer, camper, motor home, vehicle, or tent (22%); unknown (18%); parking lot (<12%); boat (<12%).

Hospitalization and Hyperbaric Treatment Datasets

CDC NEPHTN - Hospitalizations

Data Collected

Washington resident hospitalizations for 2000-2021 were included. Data met the 2013 CSTE case definition for a "Confirmed" or "Probable" case of acute CO poisoning in administrative datasets. Rates were age-adjusted by the direct method using 2000 U.S. standard population. P from ACS Annual County resident population estimates.[54]

Data Limitations

No exposure cause information was included. Records are selected using primary/other diagnosis codes and represent admissions (not individuals admitted). Transfers between hospitals are not excluded. Most out-of-state admissions are excluded; admissions for border counties may be underestimated. Data from Veterans Affairs, Indian Health Services and institutionalized (e.g., prison) populations are not included.

In 2015, ICD-10-CM replaced ICD-9-CM, impacting classifications for hospital discharge, ED, and outpatient records.[55]

Data Availability

Data were available publicly from the CDC NEPHTN database.

Tracking and Reporting Mechanism

See CDC NEPHTN – Mortalities.

Attributed Exposure Sources (CDC NEPHTN – Hospitalizations, 2000-2021)

No data showing source of CO are available in this dataset (only counts).

Washington DOH CHARS

Data Collected

The CHARS dataset was not analyzed in this report due to time constraints. However, data from the CHARS dataset are aggregated into the CHAT and WTN datasets.

The Washington DOH CHARS program collects record level information on inpatient and observation patient community hospital stays.[56] The dataset includes demographic information.

[54] NEPHTN Metadata Profile Report

[55] NEPHTN Data Explorer

[56] CHARS (Washington DOH)

Data Limitations

Hospitalizations only include acute exposures.

Data Availability

Data are accessible through Washington DOH CHS via data sharing agreements.

Tracking and Reporting Mechanism

While CHARS data are provided to multiple programs, the CHARS program is not aware of a process by which the CO exposure data would be regularly reviewed.

Attributed Exposure Sources (Washington DOH CHARS)

Data from the CHARS dataset were not analyzed for this report due to time constraints.

Washington DOH CHAT - Hospitalizations

Data Collected

Counts and age-adjusted rates[57] of inpatient/observation hospitalization discharges from 2016-2020 were included. This dataset provided additional granularity beyond the WTN dataset without the need for a DSA. Also see Washington DOH CHAT - Mortalities.

Data Limitations

Limited cause information (diagnostic code only) was included. The dataset did not designate cases as fire-related or intentional. Hospitalizations only include acute exposures. The CHAT dataset does not include military, Veterans Affairs, or tribal hospitals; ED visits without hospitalization; or an estimated 15% from some counties where patients go out of state.

Data Availability

See Washington DOH CHAT - Mortalities.

Tracking and Reporting Mechanism

While the CHAT program is not aware of all uses of the data, the program is not aware of a process by which CHAT CO exposure data would be regularly reviewed.

Attributed Exposure Sources (Washington DOH CHAT – Hospitalizations, 2016-2020)

- 39% gas engine/motor pump exhaust (“motor vehicle”)
- 23% unspecified
- 21% industrial/other
- 9% “utility gas” (acetylene/lighting/heating/cooking/water)
- 7% other domestic fuels (coal, coke, kerosene, wood)

Washington DOH WTN - Hospitalizations

Data Collected

Age-adjusted rates per 1,000,000 people and 95% confidence limits[57] in 2000-2020 data, aggregated over five years, were included. Data include Washington residents with in-patient stays at state-licensed acute care hospitals in Washington. CO poisoning hospitalizations met the CSTE surveillance case definition for a "confirmed" or "probable" case of acute CO poisoning in administrative datasets.[58] Data were categorized as fire-related, non-fire-related, or unknown based on diagnosis codes.[58] Data labeled "fire-related" and "non-fire-related" were restricted to unintentional cases only. Also see Washington DOH WTN – Mortalities.

Data Limitations

No causal information was included. Hospitalizations only include acute exposures. Hospitalization data are primarily billing data. Data may include transfers. Records from federal hospitals including the military, rehabilitation facilities, or state psychiatric hospitals were not included. Data from some counties are not reported because more than 15% of hospitalizations are estimated to occur outside of the state or at federal hospitals. Due to a change in ICD coding, WTN did not post data for aggregates of years that include 2015.[59]

Data Availability

Data are available to anyone through WTN's web portal.

Tracking and Reporting Mechanism

See Washington DOH WTN – Mortalities.

Attributed Exposure Sources (Washington DOH WTN – Hospitalizations, 2000-2020)

No data showing source of CO are available in this dataset (only counts).

Virginia Mason Hyperbaric Chamber Case Data

Data Collected

Virginia Mason hyperbaric chamber treatment case files were included from 2013-2023 (data from 2007-2012 not included).[60] Data from routine or emergency treatments were included. Data include diagnostic code and source of exposure. The source of CO is collected by the ED and the hyperbaric chamber staff as part of the intake process.

[57] Age adjustment - Health, United States (CDC NCHS)

[58] CO Poisoning Hospitalizations - Fire Related Age-Adjusted Rate per 1,000,000 (WTN)

[59] CO Poisoning Hospitalizations – Fire Related Age-Adjusted Rate per 1,000,000 (WTN)

[60] Virginia Mason Medical Center Section of Hyperbaric Medicine.

Data Limitations

Includes acute exposures only and may include intentional exposures. Multiple visits per patient may be included separately. The facility is the only 24/7 emergency chamber in the Pacific Northwest, serving Alaska; Washington; Montana; and sometimes Idaho and Wyoming. Within Washington, there are other hyperbaric facilities, but they are wound-focused. All patients in the dataset have survived.

Data Availability

Data available upon request through a data sharing agreement.

Tracking and Reporting Mechanism

Virginia Mason reported no active tracking or prevention activities relating to CO poisoning. However, physicians from the Virginia Mason Medical Center Section of Hyperbaric Medicine have been active in researching and publishing on CO poisoning and prevention issues. Dr. Neil Hampson[61] and James Holm[62] have written dozens of papers on the subject since the 1990s.

Attributed Exposure Sources (Virginia Mason Hyperbaric Chamber, 2013-2023)

Total cases: 339.

- 22% vehicle/vehicle in enclosed space
- 20% HVAC/water heater use
- 15% generators
- 13% other equipment/machinery
- 12% heating/cooking devices
- 6% unknown source
- <6% fire
- <6% kitchen appliance
- <6% boat/boat engine

Fuels (decreasing frequency): unknown, gasoline, propane, charcoal, wood, natural gas, diesel.

Emergency Department Visit Datasets

Washington DOH RHINO

Data Collected

The RHINO program is responsible for syndromic surveillance data collection, analysis, and distribution at Washington DOH in accordance with RCW 43.70.057, which requires the

[61] Neil B. Hampson - Google ScholarNeil B. Hampson - Google Scholar

[62] James R Holm (search) - Google Scholar

automated, electronic reporting of syndromic surveillance data from all Washington State EDs. The RHINO team checks the data's quality and completeness, and once validated, forwards the data to the CDC National Syndromic Surveillance Program (NSSP).[63] As of May 2020, 100% of non-federal EDs report data to RHINO.

The dataset includes 1079 emergency department encounters for CO exposures (identified using the CDC Unintentional CO Exposure v1 syndrome definition) among Washington residents, May 2020-May 2023. The data include patient demographic information, chief complaint, and coded diagnoses.

Data Limitations

Data are received by RHINO as entered into a medical record. ED visits are expected to include mainly acute exposures. No exposures resulting in death at the scene of the exposure are included. Data only include those exposures for which an ED visit in Washington was made and may therefore include some patients from outside Washington. To ensure that data were comparable over time, visits were only evaluated starting when 100% of facilities were reporting (May 2020). Although visit information is available prior to May 2020, less than 100% of facilities were reporting, and reported visit counts are lower than real visit counts.

While completeness is relatively high for race and ethnicity (>95%), the methods of collecting this information vary by facility and may not match how a patient self-reports their race and ethnicity. (Race and ethnicity uncertainties in emergency health records have been noted previously.)[64]

Statistical Significance

Comparisons were drawn between indicated patient race, ethnicity, age, and sex from RHINO ED visits and race, ethnicity, age, and sex classification percentages of the Washington population in the U.S. Census 2022 ACS. It is important to understand that there are some caveats with this analysis; notably, the datasets differ in that they represent ED visits (RHINO) and individuals (U.S. Census).

RHINO data, including race, ethnicity, age, and sex, are collected from electronic medical records. Data completeness and accuracy are reliant on collection in the medical record.

The statistical significance of the comparisons was evaluated using a test of proportions.[65] This method assumed that sampling within both datasets was random and did not take into account error in the datasets. The reflected uncertainty was greater when sample sizes were smaller. Statistical evaluations were made at the 95% confidence level.

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[63] More information available at Syndromic Surveillance (RHINO), Washington State Department of Health

[64] Yemane, L.; Mateo, C. M.; and Desai, A. N. (2024). Race and Ethnicity Data in Electronic Health Records—Striving for Clarity. *JAMA Netw Open 7*(3), e240522. doi: 10.1001/jamanetworkopen.2024.0522

[65] Choi, S. C. and Stablein, D. M. (1982). Practical Tests for Comparing Two Proportions with Incomplete Data. *J Royal Stat Soc, Series C (Applied Statistics) 31*(3), 256-262. doi: 10.2307/2347999 (Equation 2)

Other estimates of error have been calculated around U.S. Census data. Error estimates about the Demographic and Housing Estimates can be evaluated with different metrics, including the margin of error calculated over replicate estimates and the over/undercount errors for designated race groups. Demographic values also varied between years included (2020-2023). For 2020 U.S Census and 2021-2022 estimates, margins of error were <1%; differences between years were <2%; and a Pew Research study[66] that demonstrated over/undercount errors were up to 5.6% for designated race groups in 2020.

Data Availability

Data were accessed through a Data Sharing Agreement between RHINO and the School EH&S and IAQ Program. The RHINO program partners with many organizations to share and use data for public health action. Please reach out to RHINO@doh.wa.gov to discuss any questions about the feasibility of using RHINO data to support your work.

Tracking and Reporting Mechanism

The RHINO team reviews collected unintentional CO exposure ED visit trends within a cold-related illness report that is generated whenever the state experiences a cold snap or on request. The RHINO team monitors the data and would report out if there were significantly more visits than usual, based on a comparison to a four-week baseline.[67]

[66] 2020 census quality: Key facts | Pew Research Center

[67] Source: Syndromic Surveillance (RHINO), Washington State Department of Health, conversations with RHINO team.

Attributed Exposure Sources (RHINO)

Of the 1079 ED visits, 889 were unintentional, non-fire-related CO exposures (Table 2).

Table 2. Cause categories of ED visits.

Source	Count	Percentage
Exhaust - motor vehicle[a]	101	11%
Fuel powered heater/cooking[b]	73	8%
Fuel powered appliance malfunction[c]	54	6%
Fuel powered generator	50	6%
Fuel powered tools/equipment[d]	34	4%
Exhaust - other diesel[e]	18	2%
Gas leak[f]	18	2%
Exhaust - other engine/fuel	<10	2%
Exhaust - boat	<10	2%
Fire/smoke inhalation - unknown	<10	2%
Unknown exhaust exposure	<10	2%
Burning or melting - food/cooking	<10	2%
CO alarm	<10	2%
Burning or melting - drugs	<10	2%
Burning or melting - smoking/secondhand smoke	<10	2%
Exhaust - jet	<10	2%
Fuel powered lift	<10	2%
Unknown[g]	277	31%
Unknown CO exposure	237	27%

Percentage is of all unintentional, non-fire-related CO exposure ED visits.

[a] Exposure to car/truck exhaust.

[b] Exposure to exhaust from grills, wood-burning fireplaces, and other fuel powered heaters/cooking devices.

[c] Exposures associated with natural gas stoves and other appliances.

[d] Exposure to exhaust from tools or equipment such as pressure washers, concrete saws, other saws, concrete mixers, lawn mowers, carpet steamers, skid steers, air compressors, or unspecified tools/machines/motors. Gas generators were listed separately.

[e] Exposure to diesel exhaust from an unspecified engine/motor. Most visits in this category occurred on the same evening and can be attributed to a diesel engine aboard a submarine.

[f] Visits for which original data indicated a gas leak with no specific fuel or exhaust source details. This category may include exposures to gases other than CO.

[g] visits with no clear diagnosis and visits with CO exposure diagnoses but also many other diagnoses.

[h] visits for which no clear cause was indicated, but a CO exposure was indicated in the original data.

Location

While mostly unknown/unidentified, the locations of ED visits were **mainly in the patient's home** (161 visits, 18% of visits). Other locations associated with ≥10 visits were (descending frequency): workplaces; vehicles; dwellings other than or not specified as the patient's home; temporary dwellings including trailers, campers, tents, and RVs; garages, shops and sheds; and boats and

ships. Note that at least 15 visits categorized as occurring at a boat/ship location were from the same incident. Other locations associated with fewer than 10 visits included vacation homes, outside locations, schools, businesses such as stores, airplanes, and care facilities and shelters.

At-Risk Groups: Designated Race and Ethnicity

As noted above, there are some caveats with the comparison of RHINO and U.S. Census data presented here; notably, the datasets differ in that they represent ED visits (RHINO) and individuals (U.S. Census). See more in the "Dataset limitations" and "Statistical significance" sections of Appendix A: CO Exposure Datasets, Tracking.

Amongst the ED visits with the patient's race designated, there was a disproportionately high number of people designated as "Other Race" compared to the Washington state population (5% higher; statistically significant; p=0.002) (Table 3). However, no additional information is present to identify disproportionately impacted populations. While not statistically significant, the proportions of patients designated as "Black or African American" or "White" were also higher than those in the state population (both were 3% higher; p>0.24 and p>0.06). Conversely, but again not statistically significantly, the proportions of patients designated as "Asian" and "Multiracial" were lower than those in the state populations (7% and ≥11% lower, respectively; p>0.23 and p>0.42).

Table 3. Designated race of patient in ED visits.

Designated Race	Count	Percentage	State	*p*-Value
White	617	69%	66%	0.067
Other Race	112	13%	6%	0.002
Black or African American	61	7%	4%	0.254
Unknown	44	5%	--	
Asian	27	3%	10%	0.238
American Indian or Alaska Native	14	2%	1%	0.928
Native Hawaiian or Other Pacific Islander	<10	<2%	1%	0.911
Multiracial	<10	<2%	13%	0.417

Percentages are out of all unintentional, non-fire-related CO exposure ED visits.

"State" represents the percentage of the Washington state population self-identified as each designated race.[68]

Values in yellow indicate a statistically significant difference between the ED visits and the U.S. Census data[68], as evaluated using a test for comparing two proportions, following the statistical p-values shown, and evaluated at p<0.05.

Amongst CO exposure ED visits of people identified as "Other Race", the exposure causes were similar to those identified for all visits, with 10 or greater visits marked as "exhaust – motor vehicle", and unknown causes. **Further investigation would be needed to accurately identify susceptible populations such as medical records requests and patient interviews.**

[68] 2022 U.S. Census ACS Demographic and Housing Estimates

The differences in numbers of people identifying within these designated race groups may be explained in part by the difference in sources of information and question format between the RHINO dataset source and the U.S. Census questionnaire/estimates. While the "race" categories in the RHINO dataset and the presented results of the 2020 U.S. Census are similar, people making the selections may have interpreted the available choices differently.

In the RHINO dataset use, "race" is defined using the PHVS_RaceCategory_CDC value set: "American Indian or Alaska Native", "Asian", "Black or African American", "Native Hawaiian or Other Pacific Islander", "Other Race", and "White"; the subject may select more than one designation. "Unknown" and "Multiracial" were also options included in the dataset, indicating that no selection was made and that multiple selections were made, respectively.

The race data presented from the U.S. Census, in 2020, used the following race categories: "American Indian and Alaska Native alone", "Asian alone", "Black or African American alone", " "Native Hawaiian and Other Pacific Islander alone", "Some other race alone", "White alone", and "Two or more races".[69] Revisions to the federal standards governing race and ethnicity questions have recently been made to include the minimum category of, "Middle Eastern or North African".[70]

Amongst the ED visits, **Hispanic or Latino people in Washington were not disproportionately impacted, as indicated in the RHINO dataset**. Of the 889 unintentional, non-fire-related CO exposure visits, 121 (14%) were amongst people identified as Hispanic or Latino; the same percentage of people self-identified as "Hispanic or Latino (of any race)" in the state of Washington, according to the 2022 U.S. Census estimates. While the "ethnicity" categories in the RHINO dataset and the presented results of the 2022 U.S. Census estimates are similar, people making the selections may have interpreted the available choices differently. In the 2020 U.S. Census, results were presented as being "Hispanic or Latino (of any race)" or not.[69] In the RHINO dataset, "Ethnicity" is defined using the PHVS_EthnicityGroup_CDC value set: "Hispanic or Latino" and "Not Hispanic or Latino". "Not Reported/Unknown" was also an option in the dataset.[71]

At-Risk Groups: Age

Amongst the ED visits, **people aged 18 or over in Washington were disproportionately impacted**, as indicated in the RHINO dataset. This disproportion was statistically significant (p=0.001). Of the 889 unintentional, non-fire-related CO exposure visits, 744 (84%) were aged 18 or over, compared to 79% in the state of Washington, according to the 2022 U.S. Census estimates.[68] This is in line with results from the Global Burden of Disease Study 2021 results, which demonstrated that the 50–54-year age group, out of all ages, had the greatest number of deaths due to carbon monoxide poisoning.[42]

[69] 2020 State Profile Washington, U.S. Census

[70] OMB Publishes Revisions to Statistical Policy Directive No. 15 | OMB | The White House

[71] RHINO Data Description, Washington State Department of Health

At-Risk Groups: Sex

Amongst the ED visits, although a higher number of people designated as "male" compared to the Washington state population was observed, it was not statistically significant (1% higher with p=0.561). Likewise, the number of visits of people designated as female was lower compared to the Washington state population (2% lower with p=0.575).

No information about gender identity was available.

Exposure Patterns in Time: Year

Only two quarters of 2020 and 2023 were included in the dataset, so it was not possible to look for trends including those years. No trends were therefore determined across years.

Exposure Patterns in Time: Quarter

Amongst the unintentional, non-fire-related CO exposure ED visits, the numbers of visits were slightly higher in the colder times of year (Oct-Mar). However, there were still visits in the warmer months (18% in Apr-Jun; 21% in Jul-Sept). Note that only six months of 2020 and 2023 were included in this dataset, so it was not possible to look for trends including those years (only 2021 and 2022 quarters were considered). Motor vehicle exhaust, fuel powered heating/cooking, and fuel powered tools/equipment were causes of exposure during both warm and cold months.

Poison Center Datasets

WAPC (Washington Poison Center)

Data Collected

Individual observations from calls made to the WAPC 2013-2023 relating to CO exposure were analyzed (2006-2013 not analyzed). Callers include health care facilities, medical professionals, Washington residents, and others. Variables include a brief description of concern, caller type, exposure site, some demographic information, date, and outcome type. Analysis was limited to records indicating a CO exposure and a minor medical outcome.[48]

Data Limitations

Calls regarding concerns do not necessarily represent exposures or poisonings. Reporting to WAPC is voluntary and data therefore most likely under-represent injuries.

Data Availability

The WAPC data cannot be shared with other parties without a direct data use agreement and approval from WAPC.[72]

Tracking and Reporting Mechanism

There are a few different ways that emerging trends might be identified from WAPC data:[73]

All data are uploaded to a national database, and at the national level, there is monitoring in place to look for areas of concern. On a local level, WAPC might identify certain trends if noted by the poison specialists in the call center, but there is not a blanket analysis looking at all trends in place at the local level per se. It is more typical that areas of interest or focus are identified, and the data is analyzed to obtain further insight into that area. A significant increase in the number of CO exposures would likely be noticed by call center staff, since that is a particularly toxic substance and many patients are managed in health care facilities; however, the WAPC does not currently have a routine analysis of numbers of exposures to that substance in place.

WAPC is interested in providing insight for partners, including periodic analysis of data. The WAPC public education department is experienced in prevention campaigns and regularly uses call center data to support their work.

Attributed Exposure Sources (WAPC)

Burning or Melting Plastic, Food or Cooking Implements, Other Items (51% of Calls with Identified CO Source)

- Location: This may occur outside the home.
- Note: Assumed to be low CO poisoning risk. Most incidents were categorized as minor effect or minimal clinical effects possible. There is limited research on CO generation from burning plastic; one paper demonstrated that concentrations could be greater than air quality guidelines in a small/unventilated space (WHO, NAAQS).[74]

Exhaust from Motor Vehicles, Diesel/Diesel Engines, and Other Engines or Fuel (16%)

- Location: Possibly outside the home.

[72] Find more information at the Poison Center Data – Washington Poison Center webpage.

[73] Language excerpted from conversations with WAPC staff.

[74] Busker, R. W.; Hammer, A. H.; Kuijpers, W. C.; Poot, C. A. J.; Bergers, W. W. A.; Bruijnzeel, P. L. B. (1999). Toxicity testing of combustion products of polyurethane and polyvinylchloride. Netherlands Organization of Applied Scientific Research. https://apps.dtic.mil/sti/tr/pdf/ADA362007.pdf.

- Sources, descending order of frequency: unknown gas/exhaust (50%), diesel exhaust/fumes (23%), car exhaust (17%), truck exhaust (all others <8%), jet exhaust, unknown engine/motor exhaust, unknown propane exhaust, vehicle exhaust, bike/motorcycle exhaust, boat exhaust.

Fuel-Powered Heating and Cooking (9%)

- Location: Possibly outside the home. Of the 35 cases, 11 were not in the patient's own residence, and were instead in another residence, public area, or workplace.
- Sources, descending order of frequency: Propane heater (43%), barbecue/grill, wood burning, charcoal, unknown fireplace/firepit, propane stove, natural gas fireplace, electric heater, unknown kerosene, unknown propane, unknown stove.

Fuel-Powered Tools, Equipment, including Lifts and Generators (8%)

- Location: Possibly outside the home
- Sources, descending order of frequency: Generator exhaust (53%), unknown machine/engine exhaust (all others <28%), fuel-powered lift, fuel-powered saw, pressure washer, concrete machine exhaust.

Fuel-Powered Appliance Malfunction (8%)

- Location: Possibly outside the home (e.g., workplace).
- Sources, descending order of frequency (all <10 cases): furnace, natural gas stove, natural gas exhaust leak, laundry machine, hot water heater, multiple appliances, radiator.

Fire/Smoke Inhalation (7%)

- Location: Possibly outside the home
- Sources, descending order of frequency: House/kitchen fire (94%), other fire/smoke inhalation (4%), soot exposure (all others <2%), unknown fire/smoke inhalation, wildfire.

Workplace Datasets

L&I – WA FACE (Washington Fatality Assessment and Control Evaluation)

Data Collected

Reports of investigated fatalities available on the L&I website were reviewed, as were data relating to CO (1998-2023). Washington is one of seven states that receives funding from NIOSH to track fatal work-related traumatic injuries. WA FACE's goal is to prevent work-related fatal injuries through tracking, investigations, and prevention. To track work-related fatal injuries, WA FACE collects basic information on all work-related traumatic fatalities in the state, including worker and employer demographics, cause of injury, and a short description of the incident. This information comes from the L&I DOSH, L&I workers compensation claims, L&I's Bureau of Labor Statistics group, Washington DOH, public safety officials, newspapers, medical examiners, coroners, and

other sources. WA FACE also conducts voluntary in-depth site investigations of some fatalities with a focus on finding root causes.[75]

Data Limitations

Reports are only written on those fatalities investigated by the WA FACE program, based on requests or observed data trends. This includes workplace fatalities where the employer chose to participate in a voluntary investigation.

Data Availability

Reports of investigations of fatalities are available online.[75] Additionally, a database of fatalities was available upon communication with WA FACE.

Tracking and Reporting Mechanism

L&I FACE external reports are prompted by data as well as requests. Once an investigation is complete, WA FACE publishes a report that includes a short summary, details of contributing events and factors, the cause of death, and recommendations for prevention and how to protect workers from similar hazards.

Attributed Exposure Sources (WA FACE)

Three fatalities were reported in this workplace dataset due to CO exposure between 1998 and 2024.[75] Causes of death were as follows:

- In April 2006, a 35-year-old White Hispanic man from Mexico was cleaning a carpet at a facility where he was able to drive his work vehicle inside. He closed the building's doors and began using the gas-powered carpet cleaner which used the fuel from his vehicle. He was overcome by CO. (Source of CO: fuel-powered tool or equipment, carpet cleaner.)
- In May 2012, a 25-year-old White Hispanic man from Mexico was using a gasoline engine powered pressure washer inside the wheelhouse of a docked commercial fishing vessel to clean up paint chips. He was overcome by CO. (Source of CO: fuel-powered tool or equipment, pressure washer.)
- In January 2023, a semi-truck driver who had slept overnight in the truck's sleeper berth was found having difficulty breathing, walking, and standing. He was taken to the hospital, but he died shortly after from CO poisoning. The driver was most likely poisoned by CO from a single-burner butane cooking stove found in the truck. (Source of CO: fuel-powered heater/cooking.)

L&I – SHARP (Safety & Health Assessment & Research for Prevention) – Toxic Inhalation Surveillance System

[75] Work Related Fatalities (WA FACE) (L&I)

Data Collected

Data were gathered and presented in the form of a report for this Washington state interagency CO work group (SHB 1779 23-24) by the L&I SHARP toxic inhalation surveillance system[76] (report link below). Exposures included were from 2017-2022. In the report, the CO surveillance methods and trends in exposures for 2017-2022 were summarized by industry, occupation, and source. The report includes data from 2021-2022 not previously published.

The toxic inhalation surveillance system characterizes inhalation exposures from vapor, gas, dust or fume that may result in either acute injury or chronic disease. The primary data source is workers' compensation data. In Washington, nonfederal employers are required to participate in L&I's State Fund insurance program unless they meet specific requirements to self-insure or are covered under an alternative workers' compensation program. The State Fund provides coverage for about two-thirds of the workers in the state and 99.7% of all employers.

Potential cases are captured from the workers' compensation data using injury narrative keywords, International Classification of Disease (ICD-10-CM) codes, and Occupational Injury and Illness Classification System (OIICS) codes. The case definition for a CO exposure is a known or suspected exposure as stated by the employer, worker, or worker's physician. The case definition does not require specific symptoms or medical outcomes, for example an abnormal blood level for carboxyhemoglobin provides supporting evidence to confirm a case but is not required to meet the case definition.

Data Limitations

Data in the work group's report include low-dose cases of CO exposure. However, not all exposures are reported to L&I, and workers' compensation data significantly underestimates the burden of CO poisoning to Washington's workers.

Data Availability

A report was prepared by L&I specifically for this work group. It is available publicly here: Occupational toxic inhalation of carbon monoxide among Washington workers, 2017 – 2022.

Tracking and Reporting Mechanism

Washington's toxic inhalation surveillance system was established in January 2017 to characterize toxic inhalation exposures that may result in either acute injury or chronic disease. The sole data source for the surveillance system is the L&I workers' compensation system. The program describes toxic inhalation exposures as reported through workers' compensation claims, identify clusters of related exposures, and provide detailed data tables by industry and occupation. These results can be used by employers, trade associations, and public health entities interested in

[76] About SHARP (L&I)

developing prevention activities. The goal of the surveillance system is to inform targeted prevention activities and reduce the burden of preventable toxic inhalation exposures.[77]

Attributed Exposure Sources (L&I SHARP)

507 cases were reported between 2017 and 2022.

- Vehicle (car and truck) (43% of reported cases)
- Fuel-powered tools and equipment (18%)
  - Forklift, gas-powered (6% of all reported cases)
  - Saw, gas-powered (5%)
  - Pressure washer (4%)
  - Generator (2%)
  - Air compressor (<2%)
  - Sandbag filling machine (<2%)
- Heater or furnace (10%)
- Fire or smoke (7%)
- Airplane engine (3%)
- Fryer, grill, or oven (3%)
- CO stored in holding tanks or cylinders (2%)
- Welding gases (<2%)
- All other/unknown sources (12%)

Industries (top 3): public administration (including police) (19% of all cases), transportation & warehousing (14%), construction (12%)

Occupational groups (top 3): transportation and material moving (21% of all cases), protective service (16%), construction and extraction (10%).

Amongst protective service occupational CO exposures, the number of cases increased between 2017 and 2019 (18 to 31 cases) but decreased steeply in 2020 and remained similarly low (<10 cases). This may have been in part due to the COVID-19 pandemic but could also have been due in part to responses to exposures.

[77] Surveillance of toxic inhalation for Washington workers, 2017 – 2020, Publication # 64-30-2021, August 2021 (L&I)

L&I – DOSH (Division of Occupational Safety & Health) Compliance Inspections

Data Collected

2007-2020 DOSH inspections were included in the analysis. L&I has designated authority and responsibility for ensuring compliance with Chapter 49.17 RCW, the Washington Industrial Safety and Health Act (WISHA). Within L&I, DOSH is the designated representative for the implementation and enforcement of WISHA. Inspections and documentation of inspection case files are part of this enforcement process, creating a system of tracking notifications of workplace hazards.[78]

Inspections may be unprogrammed inspections scheduled in response to reports of suspected alleged hazardous working conditions at a specific worksite (also for follow-up or monitoring). Programmed inspections of worksites have been scheduled based upon objective selection criteria, normally generated using worker's compensation data for individual employer accounts. DOSH also uses industry, hazard, claims, and employer history data to identify employers and/or industries with high potential for hazards that could cause serious injuries.

In accordance with RCW 49.17.110, any employee or representative of employees who in good faith believes that a violation of a safety or health standard exists, may file a complaint with L&I requesting an inspection of the workplace. DOSH receives notice of alleged workplace hazards through a variety of sources. "Complaints" (formal or informal) can include notices from current or former employees, representatives of employees, or employees of other companies exposed to hazards at a workplace identified in the complaint. "Referrals" can include allegations of a potential workplace hazard or violations which come to the attention of L&I personnel or are received from other government agencies, other L&I staff, the media, and any other named or anonymous sources.

A formal complainant's confidentiality will be maintained by DOSH only if it has been specifically requested. Informal complaints and referrals are not confidential.

Complaints or referrals must be evaluated promptly to determine whether an inspection will be conducted. If a decision is made to inspect, the inspection must be conducted as soon as possible, but no later than 15 working days for complaints or referrals alleging serious hazards; or 30 working days for complaints or referrals alleging general hazards.

Data Limitations

Only workplace exposures are included. Many observations in the dataset are driven by a complaint system, which may not be representative of worker exposures in the state of Washington. Only observations with CO measurements were included in this dataset.

[78] DOSH Compliance Manual (L&I) (PDF)

Data Availability

Data are available upon request from L&I.

Tracking and Reporting Mechanism

Inspections of complaints or referrals can result in resolving underlying exposure causes. Data are additionally reviewed by the WA FACE program. DOSH responds directly to complaints, referrals, and employer/healthcare professional reports. The response consists of inspecting workplaces and/or reviewing inspection reports of exposures (reports are not necessarily about an injured worker or involve measurements). Employers generally abate hazards following DOSH citations and recommendations.

Attributed Exposure Sources (L&I DOSH)

- Fuel-powered tools and equipment (44%)
  - Fuel-powered forklifts or manlifts (often warehouse/industrial) (22%)
  - Fuel-powered floor equipment (cleaning, buffing, etc.) (12%)
  - Other/multiple fuel-powered pieces of equipment (often warehouse/industrial/construction site) (<10%)
  - Fuel-powered generator (<10%)
  - Fuel-powered pressure washer (<10%)
- Motor vehicle exhaust (20%)
  - Fuel-powered vehicles (cars, trucks, buses, RVs, motorcycles) (11%)
  - Vehicles running/idling at loading docks (<10%)
  - Vehicle exhaust leaks (inside vehicles) (<10%)
  - Idling/running of vehicles near buildings without sufficient ventilation (<10%)
  - Exposure in/near vehicles due to proximity of workers to exhaust (<10%)
  - Parking garages with insufficient ventilation (cars, trucks, buses, RVs, and motorcycles) (<10%)
- Unknown/unspecified source (<10%)
- Manufacturing (<10%)
  - Manufacturing processes that produce emissions (<10%)
  - Plastics manufacturing without sufficient ventilation (<10%)
  - Use of gas-fueled torches in enclosed spaces (example - glass-making) (<10%)
  - Use of welding equipment in enclosed spaces (<10%)
- Fuel-powered heating/cooking (not incl. gas stoves) (<10%)
  - Use of wood/pellet combustion for grilling/smoking/heat in enclosed spaces (<10%)
- Appliance malfunction (<10%)
  - Improper or malfunctioning ventilation in/from kitchen (<10%)
  - Fuel-powered furnace, boiler, or heater in enclosed spaces (<10%)
  - Blocked/disconnected gas-powered laundry dryer exhaust ventilation (<10%)

Use of go-carts or RC cars in enclosed spaces (<10%)

Health Behaviors Datasets

Washington DOH/CDC BRFSS (Behavioral Risk Factor Surveillance System)

Data Collected

BRFSS is a yearly survey that measures changes in the health of people in Washington. It is the longest continuously running phone survey in the world. It collects information on certain health factors like tobacco use and insurance coverage. The survey has included questions about behaviors related to CO detectors and generator use.

Data Limitations

Questions relevant to this report were only asked in prior years: 2006, 2009. Due to the limited number of responses to these relevant questions, data were not used in this report.

Data Availability

Data are available through Washington DOH.[79]

Tracking and Reporting Mechanism

N/A

Attributed Exposure Sources (BRFSS)

No CO exposure source data in this dataset.

[79] Behavioral Risk Factor Surveillance System (BRFSS) (Washington DOH)

Appendix B: Building Codes, CO Alarm and Detection Requirements

Historical CO Exposure Prevention Efforts in Washington

Exposures *outside the home* were the focus of this work group, but building codes relevant for CO poisoning prevention are discussed here, including in non-residential buildings.

In 2009, in response to high CO exposure rates during power outages (including during the December 2006 windstorm in the Puget Sound area), [80] the Washington state legislature required (RCW Section 19.27.530) that the Washington State Building Code Council adopt into code requirements for CO alarms. CO alarms were required in the 2009 Washington state building codes, with deadlines for installation of January 1, 2011 in all newly constructed residential buildings, and by January 1, 2013 in existing residential buildings.[81] Institutional occupancies were added to the 2012 Washington State building codes.[82] CO alarms were required without exception, even in homes without fuel-powered appliances or attached garages, as well as other non-residential spaces. This was in response to the findings of a CO Poisoning Prevention Planning Work Group in Washington that poisonings were occurring as a result of fuel-powered devices being used inside the home.[83] Classrooms in educational occupancy buildings were also required to have CO alarms in the 2015 Washington state building code adoptions, with specific requirements for transmission of the alarm signals so school personnel can hear them.

In the current state building codes CO detectors are not required for many spaces, other than residences, where there is no fuel-burning appliance/fireplace or attached garage.[84] In this way, the code does not prevent some exposures caused by fuel-burning devices brought indoors.

In addition to building codes, the federal Department of Housing and Urban Development (HUD) was called on (H.R. 1690) to require CO alarms in public housing (effective in 2021).[85]

CO Alarm Thresholds

The National Fire Protection Agency (NFPA) Research Foundation is currently reviewing their CO alarm and detection thresholds.[86] The equation underlying the UL 2034 Standard for Safety for Carbon Monoxide Alarms is based on exposures of young, healthy adults resulting in CO blood

[80] notes on RCW Section 19.27.530

[81] Understanding the Washington State CO Alarm Laws, Washington State Department of Commerce

[82] Carbon Monoxide Alarms | SBCC

[83] Source is no longer live: National Environmental Public Health Tracking - Washington's Success, CDC

[84] Chapter 9 Fire Protection and Life Safety Systems - 2021 Washington State Fire Code (International Code Council)

[85] HUD Issues Notice CPD-22-15: Carbon Monoxide Alarms or Detectors in HOPWA-Assisted Housing - HUD Exchange

[86] A Review of the Carbon Monoxide Alarm and Detection Thresholds, March 2024

metabolite levels exceeding 10%. Alarms following the UL 2034 standard alert when one of the following set of concentrations and duration are reached:[87,88]

- 70 ± 5 ppm for 60 to 240 minutes
- 150 ± 5 ppm for 10 to 50 minutes
- 400 ± 10 ppm for four to 15 minutes

And cannot alarm below the following test points:

- 30 ± 3 ppm for 30 days
- 70 ± 5 ppm for 60 minutes

Note that at concentrations below 150 ppm, a person would be exposed for at least 60 minutes before the alarm sounded, and the alarm would never sound at concentrations below 30 ppm.

CO Exhaust Ventilation Requirements where Vehicles Idle

Mechanical ventilation is required in Washington state for enclosed spaces where motor vehicles are operated (2021 Washington State Mechanical Code, Section 502.14: Motor vehicle operation). Ventilation is defined as "the natural or mechanical process of supplying conditioned or unconditioned air to, or removing such air from, any space", where natural ventilation means passive air flow through windows or other intentional openings.

Mechanical ventilation in **enclosed parking garages** is required to be operated either continuously or to be actuated by CO and nitrogen dioxide (NO_2) detectors, cycling between specific air flow rates (2021 Washington State Mechanical Code, Section 404: Enclosed Parking Garages). 2018 Washington State Energy Code - Commercial Provisions, Section C403.7.5: Enclosed loading dock and parking garage exhaust ventilation system controls further specifies that CO and NO_2 sensors must actuate fans to maintain <35 ppm CO concentrations.

For **loading docks**, the energy code specifies that occupancy sensors that speed up ventilation rates may be used instead of CO and NO_2 sensors. And ventilation rates for only enclosed parking garages, and not loading docks, are specified in the 2021 Washington State Mechanical Code. While not clearly defined, jurisdictions may apply the enclosed parking garage ventilation rate for loading docks. Some loading docks may also have substantial natural ventilation. The Seattle Mechanical Code (2018) specifies ventilation rates for both on and standby modes of the ventilation system for enclosed loading docks. This has reportedly been in the Seattle Mechanical Code for at least 20 years.[89] Loading docks would be still be subject to building code requirements for motor-vehicle-related spaces (2021 Washington State Building Code: Section 406 Motor-Vehicle-Related Occupancies).

[87] Hampson, N. B. and Holm, J. R. (2022). Comparison of four low-level carbon monoxide alarms suitable for home use or when traveling. *Undersea Hyperb Med. 49*(3), 307-313. https://pubmed.ncbi.nlm.nih.gov/36001563/

[88] UL Standards & Engagement: UL 2034 (UL)

[89] Source: conversation with Seattle Department of Construction & Inspections staff.

No specification is made for **auto repair facilities** (although there are specific direct exhaust requirements for auto repair facilities, 2021 Washington State Mechanical Code, Section 404.3: Automobile repair facilities). Where vehicles are stationary, such as auto repair facilities, a source capture system that connects directly to the motor vehicle exhaust systems is also required, with some exceptions (2021 Washington State Mechanical Code, Section 502.14: Motor vehicle operation).

Amongst L&I DOSH investigations 2007-2020, at least five were conducted in spaces that could be considered loading docks and six in auto repair spaces (97 total investigations with CO measurements).

Ice Arena Exhaust Ventilation

Ice arenas have been an area of concern for combustion emissions because of ice resurfacers used within the enclosed area. Even within the past year, there have been hospitalizations due to CO exposures in improperly ventilated indoor ice arenas in other areas of the country. According to a news article, "more than 100 people were hospitalized after [CO] levels reached levels between 200 and 400 ppm…" in a New York hockey rink in December 2023 where an ice resurfacer malfunctioned.[90] A state bill was proposed in response that would mandate tracking CO concentrations, following national guidance.[91]

Washington state has many ice arena facilities for recreational and professional use. The 2021 Washington state adoption of the mechanical code, specifies minimum outdoor air airflow and exhaust airflow rates.

Some states, including Minnesota, already require CO monitoring and responsive actions in indoor ice arenas, including evacuation.[92] Recent EPA emissions standards for ice resurfacers have also decreased CO and other emissions substantially.[91] No CO poisonings due to exposures in ice arenas were noted in datasets analyzed by the SHB 1779 23-24 interagency CO work group.

CO warning sticker on motor-driven boats and vessels

Washington Senate Bill 6364 (2005-2006) and RCW 88.02.390 established that any new or used motor driven boat or vessel sold in the state must display a CO warning sticker developed or approved by the Washington State Department of Licensing and the U.S. Coast Guard.[93] In addition, the bill prohibited operating a motor boat or vessel while an individual is "teak surfing", platform dragging, or bodysurfing behind the boat or vessel. The bill was named for two young

[90] Carbon monoxide detector sounds at Holiday Twin Rinks (WGRZ)

[91] Indoor Air Quality and Ice Arenas (U.S. EPA)

[92] Indoor Ice Arenas - MN Dept. of Health

[93] More information about the sticker is available in Chapter 308-93-146 WAC and at the Washington State Department of Licensing website.

women who were killed while "teak surfing". According to a Seattle Times article[94] about the deaths, quoting the U.S. Coast Guard, "carbon monoxide concentrations released from the backs of ski boats can be as high as 40,000 to 80,000 ppm…", while "concentrations as low as 200 parts per million can be fatal over a period of time." CDC and the U.S. Coast Guard provide additional information and guidance about CO build up at the rear of larger boats.[95]

Real Estate Disclosures

In Washington, language must be added to real estate purchase and sale disclosures about whether a home is equipped with CO alarms (RCW 64.06.020).

Outdoor Air Quality CO Concentration Standards

The National Ambient Air Quality Standard (NAAQS) levels for CO, also adopted by the state of Washington (WAC 173-476-160), are as follows:

- 8-hour avg of 9 ppm must not to be exceeded more than once per year
- 1-hour avg of 35 ppm must not to be exceeded more than once per year

Implementation for this standard is carried out by the state Clean Air Agencies (or the regions of the Department of Ecology, where applicable). Two areas in Washington were designated as maintenance areas for CO in the past, but the 20-year maintenance periods end(ed) in 2022 (Yakima) and 2025 (Spokane).[96]

Inspections of Temporary Worker Housing

The Washington DOH and L&I carry out inspections of temporary worker housing following Chapter 246-358 WAC. Among the inspection items is the provision of a maintained CO alarm in each dwelling unit with a sleeping area, in each cooking area, and following the building codes.

[94] Risky "teak surfing" blamed in lake death The Seattle Times)

[95] About CO Poisoning on Your Boat | Carbon Monoxide Poisoning (CDC)

[96] Maintenance State Implementation Plans (Washington State Department of Ecology)

Appendix C: A Note about Notifiable and Provisional Conditions

Notifiable conditions are diseases and conditions that must be reported to public health authorities by professionals and facilities. Each notifiable condition in Washington state has a designated program within Washington DOH, specific surveillance timing, and a reporter to review and respond to new data. Data designated for submission for a notifiable condition are electronically collected into the Washington Data Reporting System (WDRS). The designated program is notified when data are received.

The U.S. CDC has designated CO Poisoning as a nationally notifiable condition, and the CSTE[97] recommends that all states and territories make CO poisoning reportable in their jurisdiction. However, at the time of this report, CO poisoning is not a notifiable condition in Washington State.[98]

A **Provisional Reporting Notification** (Chapter 246-101-015 WAC) is a mechanism allowing for the state health officer to request submission of case reports, investigation reports, or other data types regarding a condition other than a notifiable condition, when they determine that information is likely to contribute to understanding, provide information necessary to prevent the condition, and improve public health. In this way, the data and data collection are reviewed. A provisional condition lasts for a period of 40 months, after which the state health officer may request that the board consider notifiable condition rule revision or discontinue the provisional condition.

[97] CSTE Position Statement on Standardized Surveillance for CO Poisoning

[98] List of Notifiable Conditions | Washington State Department of Health

Appendix D: What's Already Being Done

Ongoing Prevention Activities: Motor Vehicles and Gas or Diesel Engines

Structural CO alarms and detection systems to make elevated CO levels sensible are required in some Washington indoor spaces, but not all. The 2021 Washington state building codes require CO alarm/detection systems, including in schools and some workplaces.[99]

- **Most residential garages and sheds**[100] are not required to have CO alarms, but combustion devices are often kept and used in or near them. Some CO detection systems may not detect elevated CO well when other volatile chemicals, extreme temperatures, or humidity are present. Warning labels and messaging can be used to warn people of potential CO poisonings.
- In **loading docks**, sensor-actuated ventilation is required, with options for gas or occupancy sensors. While ventilation rates are not specifically defined for loading docks, at least five workplace investigations with CO measurements, were conducted in loading dock type spaces (L&I DOSH, *n*=97).
- Building alarms must meet safety and operation requirements of UL Standard 2034.[106]

Investigations into the cause of officer exposures in patrol vehicles, including by L&I[101] and the National Highway Traffic Safety Administration (NHTSA)[102]. Multiple law enforcement personnel in Washington state and across the U.S. reported symptoms of CO exposure while operating pursuit-rated vehicles. L&I's investigation revealed that some high-use Ford Interceptors (model years 2013-2017) were associated with Washington exposures. Exhaust leaks were identified and associated with the exposures.

Law enforcement and government vehicle fleets have addressed acute and chronic exposures through **fleet CO sensor deployment, repairs, and hybrid/electric vehicle adoption**.

- **Washington State Patrol (WSP)**: In line with recommendations from L&I[101], WSP has deployed CO monitors to all its Ford Police Interceptor patrol vehicles, set to alarm prior to workplace permissible exposure limits (PELs) set by **the Washington Industrial Safety and Health Act (WISHA)** (35 ppm) and at a high level (100 ppm). A decision tree and training have been created and are given to all new agency employees. CO data collected by WSP support that monitors have likely prevented CO exposures that could have exceeded the limits in relation to the regulations of workplace safety, with reported success in detecting

[99] See Appendix B: Building Codes, CO Alarm and Detection Requirements for more information.

[100] 2021 state building codes do require exhaust ventilation for private garages over 1000 square feet not belonging to one- and two-family dwellings and garages common for multiple units and belonging to single and multiple-unit private dwellings. CO alarms are also required for institutional and most residential dwelling units (or common areas/source areas serving them) with an attached garage (2021 Washington State Mechanical Code, ICC).

[101] CO and Law Enforcement Personnel, Oct 2018 (L&I)

[102] EA17002 Vehicle Recall Details [EA17002] NHTSA)

possible issues. Repairs to vehicles were also made in response to the discovery of exhaust manifold leaks, and WSP's Fleet Section is working with Ford on any new incidents that occur. In addition, some newer police vehicles are hybrid electric and will shut off the gas engine when the vehicle is stationary, only turning on to charge the battery intermittently.[103]

- **Local law enforcement agencies** have also taken prevention measures. For example, the Clark County Sheriff's Department and the Seattle Police Department (and broader Seattle Fleet Management fleets) have deployed CO detection devices to their vehicles.[104] Spokane Police Department vehicles are regularly checked for exhaust leaks, and vehicles will not be used until repaired if an exhaust leak is identified. Seattle Fleet Management, including the Seattle Police Department, has discontinued CO detector use in favor of preventive maintenance and the transition of all new vehicles to hybrid or fully electric.
- Other fleets have taken prevention measures. **The Washington State Department of Enterprise Services (DES)** delivered CO detectors to agencies with Ford Explorers or Interceptors owned or managed by DES Fleet Operations as a precautionary measure. This was done in response to a March 2017 technical advisory from Ford announcing that some police vehicles may exhibit an exhaust odor in the vehicle. Seattle Fleet Management has also taken prevention measures (see above).
- Commercial fleets also have some CO safety requirements. Under 49 CFR 392.66, U.S. **employers must ensure a commercial motor vehicle is not used when CO is detected.** More specifically, a vehicle cannot be used when an occupant has been affected by CO; where CO has been detected inside the vehicle; or when a mechanical condition is discovered that would be likely to produce a hazardous CO exposure to vehicle occupants.

In **workplaces**, complaints and referrals prompt L&I Division of Occupational Safety & Health (DOSH) inspections. This can include CO exposure concerns. Data are collected and inspection reports are created for later review. Claim numbers decline in response to citations issued by DOSH inspectors, according to data analyzed by an economist at L&I.[105]

There is only limited guidance around low-level CO monitors, such as CO Hazards from Small Gasoline Engines (CDC NIOSH), which recommends using personal CO monitors where potential sources of CO exist and having audible alarms at CO concentrations exceeding the NIOSH ceiling limit for CO. Research by Virginia Mason experts on low-level CO alarms for home or travel that display CO concentrations[87] has also shown that such devices are appropriate for public use. Following their investigation of exhaust leaks in police vehicles, L&I produced a CO and Law

[103] All-New Ford Police Interceptor Utility Pursuit-Rated Hybrid Offers Improved Performance, Lower Gas Costs | Ford Media Center

[104] Seattle Fleet Management, including Seattle Police Department (SPD), installed CO detectors (CO Detector, ASA) in all their gas-powered vehicles. However, CO monitors have now been replaced with preventive maintenance in the fleet, including patrol vehicles. The decision to discontinue was made in partnership with SPD for 2 reasons: 1. The original impetus to add these monitors was due to an issue flagged by Ford that was found to be only happening on equipment that was modified incorrectly – vendor was following all Ford upfitting guidelines and equipment did not have a problem. 2. All new SPD vehicles are hybrid or electric and have different operating conditions that have reduced CO concerns. Other vehicles have anti-idling equipment, as well, as part of vehicle emissions reduction efforts. (From direct communications with SPD and Seattle Fleet Management staff.)

[105] DOSH Compliance Effectiveness in Washington State, 2021-2022 (L&I) (PDF)

Enforcement Personnel factsheet (L&I) with prevention guidance for employers, including the following characteristics to look for in a CO monitor for use in a vehicle:

- Provides and stores continuous and peak CO measurements.
- Can be set to vibrate, sound, or flash an alarm signal when CO concentrations reach occupational exposure limits.
- Has a built-in calibration feature to ensure continued accurate measurement.
- Can handle rough conditions during use.

UL Standard 2034: Single and Multiple Station CO Alarms[106] was updated in 2023 so that the scope includes RVs, commercial vehicles (including semi-truck cabs), and unconditioned spaces.

Decisions and programs to incentivize electric vehicles and charging infrastructure are ongoing. According to ECY,[107] sales of electric and plug-in hybrid vehicles accounted for about 20% of 2023 Washington total vehicle sales, more than double the national average of about 10%. While the intent of this programming is to prevent greenhouse gas emissions, reduced or eliminated emissions of CO and other harmful pollutants are a co-benefit. This includes:

- The statewide 2023 Electric Vehicle Council Transportation Electrification Strategy (TES), developed following RCW 43.392.040 to ensure **electric vehicle incentives and infrastructure** are accessible and available to all people in Washington (see page 96 of the TES full report for priority policies).
- Washington's zero-emission vehicle standard, which requires that by 2035, 100% of all new passenger vehicles and light-duty trucks sold in Washington meet **zero-emission requirements**, meaning they do not release tailpipe air pollution. These include battery and hydrogen fuel cell-powered electric vehicles and plug-in hybrid vehicles with at least 50 miles of electric range.
- The transition of state fleet vehicles (Washington State Department of Commerce) to battery electric options.
- **Incentives for charging stations** through the Washington Electric Vehicle Charging Program (Washington State Department of Commerce). The Department of Commerce additionally announced grants for 5000 new charging stations in communities throughout the state in February 2024, with supplemental support from the Climate Commitment Act.
- **Grants** provided by ECY's Washington State Clean Diesel Program, such as:
  Fuel Cell Transit Buses and Electric Yard Trucks Grants that can be used to **upgrade diesel-burning trucks**, especially those that idle or exhaust in areas where people are present. Funding is through the 2023-2024 Diesel Emission Reduction Act.
  ECY's Clean Diesel Grants, which made approximately $1 million available for projects including zero emission fleets **training** pilot programs for school bus mechanics, bus drivers, and office staff; pilot student training programs for transitioning to zero emission fleets; and **replacing** diesel marine engines with all- or hybrid electric systems.

[106] Underwriters Laboratories (UL) Standard 2034: Single and Multiple Station CO Alarms (free digital view available).

[107] A record year for electric and plug-in hybrid vehicles in Washington - Washington State Department of Ecology

2023-2024 **policy proposals** to build charging infrastructure, reduce vehicle idling, and support the transition to zero emission vehicles, including school buses.
Rulemaking is ongoing for The Clean Fuel Standard (Chapter 70A.535 RCW, ECY), which will curb carbon pollution from transportation, the largest source of greenhouse gas emissions in Washington, by **reducing emissions from the production and supply of transportation fuels**. It will provide an increasing range of low-carbon and renewable alternatives that reduce dependency on oil and improve air quality.

Anti-idling technologies are being tested in emergency vehicles, including feasibility and ease of use of a variety of models (some continue to use a small amount of fuel). Research is ongoing by Argonne National Labs.[108] Some anti-idling devices have been subsidized through ECY's Clean Diesel Grant Program, which has previously worked with school buses and emergency vehicles.

Messaging is available from several resources.

- **U.S. CDC** provides a website with various resources, including posts of CO-related **U.S. CPSC** recall alerts; high quality videos, factsheets, and informational webpages; a Carbon Monoxide Poisoning Prevention Toolkit; and links to recent studies and clinical guidance resources.
- The **National CO Awareness Association (NCOAA)** brings together experts and stakeholders, including private companies, to discuss CO exposure concerns and studies. Their hosted resources (CO Safety Resources: Brochures, Checklists, White Papers) include a CO Car Safety Checklist, which highlights regular activities to keep your car safe, and a Protect the Protectors brochure, which highlights the safety of emergency professionals.

Ongoing Prevention Activities: Fuel-powered Heating and Cooking Devices, including Wood but Not Gas Stoves

ECY's Wood Smoke Reduction Grant Program helps people **scrap or recycle inefficient and highly polluting wood stoves** and replace them with more efficient, less polluting devices including electric heat pumps.

Charcoal briquette packages are required to have **CO hazard labels** (16 CFR 1500.14 -- Products requiring special labeling under section 3(b) of the act).

U.S. CPSC provides public messaging and a website with information, factsheets, and a U.S. CPSC CO Safety Toolkit. Topics include specific product hazards such as camping equipment (grills, lanterns, and stoves), generators, regular inspections of CO detectors, charcoal, and storms.[109]

There is some guidance around low-level CO monitors that can be used for personal and vehicle exposures (see above).

A voluntary standard exists requiring CO alarms in recreational vehicles (RVs). The RV Industry Association (RVIA), which reportedly represents nearly all RVs made in the U.S., requires this

[108] Argonne National Labs (Jan 2016) Case Study – Idling Reduction Technologies for Emergency Service Vehicles. ANL/ESD-16/3. https://publications.anl.gov/anlpubs/2016/03/125155.pdf.

[109] Carbon Monoxide (CPSC)

standard and inspects RV manufacturing facilities.[110] While some RV parks are reported to require the RVIA seal, the extent of this requirement is unclear. Exposures reported to have occurred in RVs, trailers, motor homes, and campers were somewhat common in exposure data, accounting for 9% of CO-related ED visits, with some reporting CO alarms sounding.

Ongoing Prevention Activities: Fuel-Powered Tools and Equipment, including Generators

Messaging is available from multiple sources.

- The **U.S. CPSC** provides some protections and messaging around generator use, including on **required danger labels on generators** (16 CFR Part 1407), hosting and regularly sending emails about **excellent resources including videos** on generator and CO safety (although their CO Safety Toolkit needs updates), sending out **free pamphlets and door-hangers to communities**[111], and facilitating **product recalls** and alerts.
- L&I provides guidance on avoiding CO exposure from forklift use: Forklift Safety Guide, L&I (PDF) and Prevent CO Poisoning from Forklifts, L&I PDF. The L&I SHARP program has published two previous analyses showing that **propane-powered forklifts in agricultural cold storage warehouses were a predominant source of CO poisoning in Washington for the period 1994 to 2005**[112,113]. The adoption of electric-powered lifts and the manufacture of cleaner burning propane forklift engines in accordance with EPA regulations (EPA 40 CFR part 1048) may have contributed to a reduction in CO cases caused by propane forklifts noted for the period 2017-2020[114]. Forklifts were still the fourth highest source of CO exposure claims 2017-2022[10], and fuel-powered forklifts or manlifts (often warehouse/industrial) are the greatest source of 2007-2020 L&I DOSH compliance investigations where CO was measured (22%).
- L&I provides guidance on avoiding CO exposure when using other fuel-powered tools. Their "CO Poisonings at Indoor Work Places" factsheet (L&I) was created in response to 11 employees poisoned by CO at 3 work places. The sheet notes that, "**Running just one propane-powered machine in a poorly ventilated space can lead to CO poisoning, even in larger spaces**…". Recommended actions include testing the air for CO during work activities and adding portable ventilation to provide fresh air. The U.S. CDC recommends that gas-

[110] NFPA 1192 Standard on Recreational Vehicles, 2018 edition. According to their website, RVIA "… represent[s] over 500 manufacturers and component and aftermarket suppliers who together produce 98 percent of all RVs made in the United States, and approximately 60 percent of RVs produced worldwide" (Meet The RV Industry Association's New Members— February 2024 | RVIA).

[111] Order printed safety guides (CPSC)

[112] Lofgren, D. Occupational carbon monoxide poisoning in the State of Washington, 1994-1999. 2002. App Occup Env Hyg (4):286-95. doi: 10.1080/10473220252826592.

[113] Reeb-Whitaker, C, D Bonauto, S Whittaker, and D Adams. Occupational carbon monoxide poisoning in Washington State, 2000-2005. 2010. J Occup Environ Hyg (10):547-56. doi: 10.1080/15459624.2010.488210.

[114] Washington State Department of Labor and Industries. Surveillance of toxic inhalation for Washington workers, 20172020. August 2021. SHARP Publication # 64-30-2021. Safety and Health Assessment and Research for Prevention Program, Olympia WA. https://lni.wa.gov/safety-health/safety-research/files/2021/64_30_2021_SurveillanceToxicInhal_20172020.pdf.

powered engines or tools not be used in enclosed/partially enclosed areas unless the engines can be located outside and away from air intakes.[115]

- **Messaging around generator safety** is available through many organizations, including Washington DOH, local health jurisdictions such as PHSKC,[116] CDC, FEMA, UL, the National CO Awareness Association (NCOAA)[117], and many others.

The CPSC **requires danger labels on generators** (16 CFR Part 1407).

The CPSC **proposed a required Safety Standard for Portable Generators** that would require sensors and automatic shut-off features. Voluntary standards currently exist, including through UL and a generator manufacturing organization.

In the 2023-2024 Washington state session, legislation was introduced toward **adopting zero-emission small off-road engines and equipment standards**, with exemptions such as generators and chainsaws. Such an adoption would be provisional and dependent upon a determination not yet made by the U.S. EPA[118].

Safety standards are enforced by L&I in Washington state workplaces. The WISHA PEL for CO in general industry limits a worker's exposure to not more than 35 parts CO ppm averaged over 8 hours, not more than 200 ppm over five minutes, and not more than 1500 ppm for any amount of time (Chapter 296-841-20025 WAC). Employers evaluate, notify on, and control employee exposures to hazardous airborne contaminants (Chapter 296-841 WAC). The safety standards for ship repairing, shipbuilding, and shipbreaking require the use of CO detectors (Chapter 296-304 WAC). L&I DOSH compliance inspections respond to complaints and referrals concerning these limits. The WISHA PEL for general industry is lower than the OSHA PEL for CO, which is 50 ppm averaged over 8 hours.

Ongoing Prevention Activities: Fuel-Powered Appliance Malfunctions

Incentive programs to choose electric appliances are ongoing, such as the Home Electrification and Appliance Rebate (HEAR) Program (Washington State Department of Commerce).

Recent **building code and policy proposals** to support the transition to electric appliances.

The state adoptions of the **building codes require CO alarm/detection systems**, including within non-residential structures such as schools and workplaces. Alarms must meet the safety and operation requirements of UL Standard 2034.[6,13] See Appendix B: Building Codes, CO Alarm and Detection Requirements.

Washington DOH and L&I inspect temporary worker housing for issues including working CO alarms (Appendix B: Building Codes, CO Alarm and Detection Requirements).

[115] Carbon Monoxide Hazards from Small Gasoline Engines | NIOSH | CDC

[116] Prevent poisoning from CO - King County, WA

[117] Generator Safety Toolkit (NCOAA)

[118] See information about related federal and California provisions in the House Environment and Energy Committee Bill Analysis.

The U.S. **CPSC recently proposed a Safety Standard for Residential Gas Furnaces and Boilers (CPSC)**, which would add safety devices on specified appliances. Despite high cost/benefit ratio for boilers and furnaces, the standard would reduce exposures, injuries, and deaths.

Research and discussions are ongoing about lowering CO alarm thresholds. Current CO alarm designs are only designed to protect people from death and do not protect against lower concentration exposure health concerns. The NCOAA, a non-governmental group, has published a white paper and continues to discuss this issue within its membership[119]. The NCOAA hosts an annual summit on CO safety.

Messaging

- U.S. CPSC **emails timely alerts** about dangers and prevention of CO exposures due to appliances and hosts online resources (anyone can subscribe to U.S. CPSC Recalls and Safety Alerts). The Invisible Killer (CPSC) is an excellent 2-pager about appliance malfunction, covering: **installing appliances following manufacturer and local codes**; and **annual inspections and services** – what to look for, such as decreased hot water supply, furnace unable to heat house or runs continuously, or unfamiliar or burning odor.
- The U.S. DOE provides a Guidance Document on Space Heating Electrification for Large Commercial Buildings with Boilers (U.S. DOE) (PDF). This document focuses mainly on **guidance for electrification strategies for fossil fuel boilers for existing buildings**, which have greater challenges than new-construction applications.

What is California doing? The California Air Resources Board (CARB) is developing and proposing Zero-Emission Space and Water Heater Standards (CARB). The concept for the standards is not to ban units, but to allow residents and businesses to purchase new zero-emission space or water heaters. Eliminating an indoor CO source is a co-benefit of this project.

Ongoing Prevention Activities: Other Factors – Storms

Programs such as the Washington Tracking Network **performing regular review** of CO exposure datasets have successfully identified past events, allowing for an examination of causes. However, no review across all datasets is being done for CO (see Section 0).

Some **messaging is disseminated prior to major storms/stormier seasons**. More local messaging could improve prevention activities.

- Washington DOH has CO exposure prevention messages ready for use. Topics include generator use, idling vehicles in enclosed spaces, using power tools and equipment in enclosed spaces, malfunctioning appliances, and maintaining CO detectors. For example:
  - Prepare now for emergencies in the fall and winter (Washington DOH) (Sept 2023)
  - Resources and emergency shelters available statewide to keep people safe and warm during dangerously cold winter weather (Washington DOH) (Jan 2024)

[119] Resources (NCOAA CO Safety Summit)

- The WSP State Fire Marshal's Office creates press releases covering fire and CO poisoning prevention topics including **holiday safety**, fireplace and chimney safety, recreational vehicle safety, **winter weather preparedness**, and using central heating systems safety.[120]
- U.S. CPSC sends messaging via email prior to CO hazard events such as winter weather (for example, they released a notice in early 2024).[121] These are sent as email notifications prior to major storms and winter weather (**in preparation for power outages and generator/heater use**).
- U.S. EPA also provides a webpage and related factsheet with QR codes describing safe practices to avoid CO poisoning during a power outage.[122]

Ongoing Prevention Activities: Other Factors – Firefighter Smoke Inhalation

Chapter 296-305-06511 WAC requires specific **personal protective equipment** for all fire department members appropriate for the risks that might be encountered while near the hazard (this cannot reduce or interfere with the effectiveness of the emergency response). Specific wildland firefighting regulations will supersede.

In 2016, L&I wrote a report to the state legislature on work-related hazardous exposures to firefighters, following SHB 1604 in 2015. In the report, L&I found that there was no existing system for firefighters to document and report such exposures. The work group extensively evaluated two **reporting systems**, the Personal Injury, Illness, and Exposure Reporting System (PIIERS) and the Washington Fire Incident Reporting System (WAFIRS). While the work group found that exposure reporting is beneficial, there was no consensus that it should be mandatory. Both PIIERS and WAFIRS are still used in Washington, and some firefighters are encouraged to voluntarily report.

Although not specific to Washington state, chronic exposures to CO near wildland fires have been documented, including basecamp staff and firefighters.[123,124] U.S. EPA has researched CO concentrations near wildfires and has begun a pilot project through which tools for monitoring CO and other pollutants can be borrowed.[125] A positive correlation between particulate matter and CO concentrations has been noted near fires, and research is ongoing.[126]

[120] https://www.wsp.wa.gov/?s=carbon+monoxide

[121] Stay Safe, While Staying Warm This Winter (CPSC)

[122] Power Outages and Indoor Air Quality (EPA)

[123] Henn, S. A., *et al.* (2019). *J Occ Eng Hyg, 16*(12), 793-803. doi: 10.1080/15459624.2019.1670833.

[124] McCleery, R. E., et al. (2011). Determining base camp personnel exposures to carbon monoxide during wildland fire suppression activities – California (NIOSH health hazard evaluation report HETA 2008-0245-3127).

National Institute for Occupational Safety and Health, Division of Surveillance, Hazard Evaluations, and Field Studies. https://stacks.cdc.gov/view/cdc/48063.

[125] Wildfire Smoke Air Monitoring Response Technology (WSMART) Pilot (U.S. EPA)

[126] EPA Expands Air Monitoring Capabilities to Support Wildfire-Impacted States, Tribes and Their Frontline Firefighters (U.S. EPA)