Background briefings on emerging issues for
fire managers from AFAC and Bushfire CRC.

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FIRE NOTE

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ASSESSING TOXIC EMISSIONS AT THE RURAL/URBAN INTERFACE

▲ The combustion of products that are likely to be burnt during a bushfire at the rural/urban interface are likely to emit smoke that is more dangerous than smoke from a forest fire.

SUMMARY

This project will assist fire agencies gain a better understanding of potentially toxic emissions and their exposure concentrations at the rural/urban interface by creating a scenario-based exposure assessment that will define exposure risks to firefighters.

Emissions were assessed by identifying the types and amount of major combustible materials in structures, houses and other objects commonly around the house. Emissions released from burning these materials were then determined and exposure potential to firefighters and communities assessed. This *Fire Note* outlines the emission products released and what this means.

Tests were conducted in laboratory experiments, with the emissions compared to those from pine. Air toxins tested included carbon monoxide, carbon dioxide, particle mass, elemental and organic carbon, polycyclic aromatic hydrocarbons, carbonyls and other volatile organic compounds. This research is essential and will underpin future field tests, which must be undertaken to validate findings within an operational context prior to development of operational guidelines.

ABOUT THIS PROJECT

The *Operational readiness of rural firefighters (air toxins)* project is part of the Occupational health and safety and surge capacity series of projects, within the Bushfire CRC *Managing the threat* program.

AUTHOR

Dr Fabienne Reisen (right), Research Scientist, CSIRO Marine & Atmospheric Research. For more information, contact fabienne.reisen@csiro.au

CONTEXT

Forecasted population growth in rural/urban interface areas will expose more residents and homes to an increased bushfire risk. As a result, fighting bushfires at the rural/urban interface is likely to become more frequent, but currently little is known about the air toxins emitted and exposure concentrations inhaled by firefighters and residents.

The materials selected for this study are commonly present in a house or surrounds, but the current knowledge on their combustion is limited. A better understanding of the type and yields of potentially toxic gases and particles released during combustion will aid in assessing exposure risks to firefighters and communities at the rural/urban interface.

BACKGROUND

The rural/urban interface is characterised by multiple fuel types, including vegetation, as well as a range of combustible materials from house structures, house contents, vehicles and other objects around a house. These burning materials are likely to emit additional toxic combustion products, and as a result may cause a greater health risk to firefighters and community members in the vicinity of the fire.

Tests on a small scale have been conducted on a range of materials present in buildings to assess the type and yield of a range of emission products. Furthermore, large scale fire tests have been conducted to assess emissions from car fires and fires within a specific room. A review of the existing literature has revealed that organic compounds were considered to present a potential health hazard, but in most studies individual compounds have either not been identified or quantified (Reisen, 2011a). Although total emissions of carbon monoxide (CO) and carbon dioxide (CO_2) dominate, hydrocarbons and volatile organic compounds are important contributors to the total emissions, and therefore likely to impact on health.

BUSHFIRE CRC RESEARCH

Experimental burns were conducted using a cone calorimeter, which is a small-scale fire test apparatus that aims to determine heat release rate, mass loss rate, ignitability, gas species and particle production rate (Leonard, 2000). Specimens sized 100mm by 100mm of various building types and furnishings were conditioned at 23°C and 50% relative humidity. The specimens were then placed into a sample holder and subjected to a radiant heat source of 25 kW/m². The tests were conducted in well-ventilated conditions with constant air supply fed into the system. The gases passed through an exhaust duct, which was lined with two sampling inlets. These were linked to a number of sampling devices to collect a range of gaseous species and particles.

A desktop study on toxic emissions from fires at the rural/urban interface has shown that wood and wood-based products make up the majority of materials burnt, followed by polymeric materials (Reisen, 2011b). As such, the materials tested in the experimental burns included a number of wood-based and polymeric products commonly found in furnishings and home contents. Most of these materials were predominantly made up of carbon, oxygen and hydrogen. Because of this, their major emissions are CO_2 and CO. However not all of the carbon is converted to CO_2 and CO; the carbon that is not is released as aliphatic, aromatic and oxygenated hydrocarbons, some of which have the potential to harm people's health.

Some of the materials such as particleboard, medium-density fibreboard, carpet and polyurethane foam contain a significant fraction of nitrogen. Burning these materials will produce hydrogen cyanide, ammonia, nitriles and nitrogenated hydrocarbons. All of these are potentially harmful to people's health.

Emissions from all materials tested were evaluated against those from pine, a natural material widely used for structural construction. For this reason, it is a good reference material against which to compare manufactured and/or synthetic materials.

RESEARCH OUTCOMES

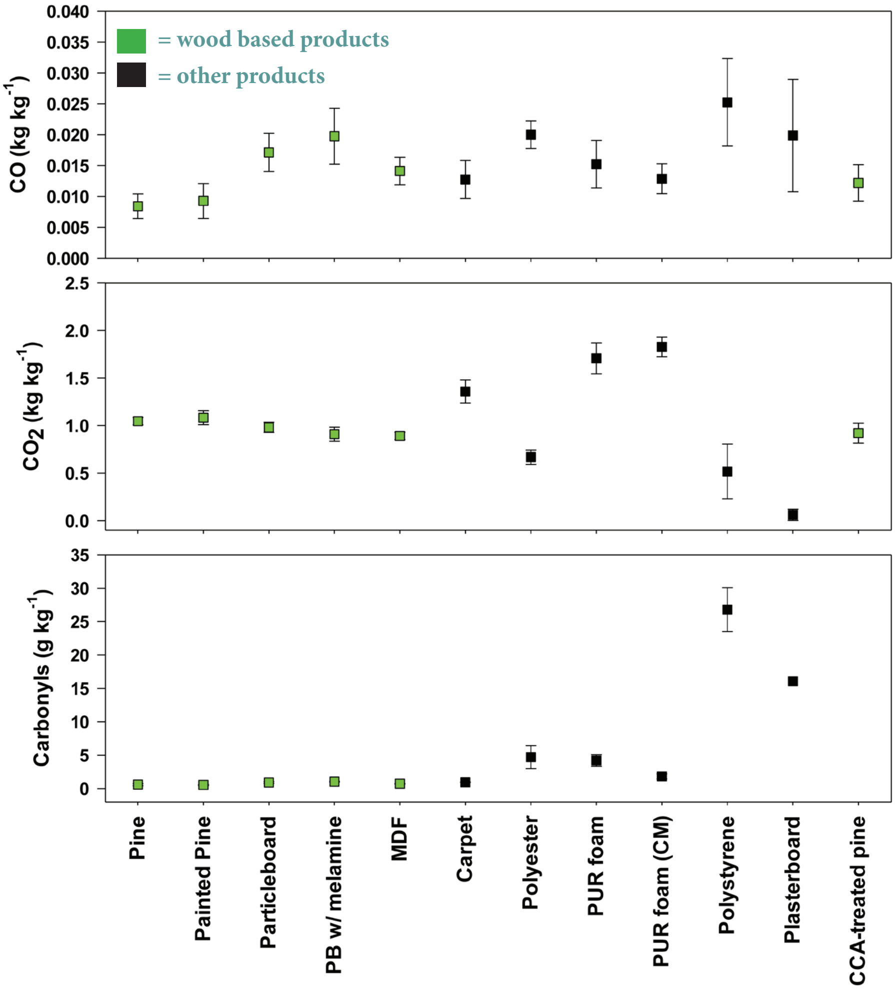
Initial findings from the experimental burns, as well as the literature review conducted prior to the tests, show that exposures to compounds emitted during combustion of materials can lead to a range of adverse health impacts. These can be classified as follows:

1. Asphyxiants (CO and hydrogen cyanide).
2. Irritants (particles, volatile organic compounds, carbonyls, nitrogen dioxide, ammonia, hydrogen chloride and sulphur dioxide).
3. Impact on the central nervous system (CO, benzene, toluene, phenol).
4. Carcinogens (benzene, formaldehyde, naphthalene, isocyanates).

Some of these toxins, in particular chlorinated and nitrogenated compounds, are likely to be more present in bushfires at the rural/ urban interface due to the types of fuels and materials burnt when compared to a forest bushfire. Other air toxins such as CO, particulate matter, formaldehyde and benzene are major air toxins emitted from both rural/ urban interface and forest bushfires.

The results from the experimental burns are summarised in Figures 1 and 2 (pages 2 and 3), which show the emission factors (defined as the amount of a compound emitted per amount of fuel consumed) of CO, CO_2, particulate matter, elemental carbon, organic carbon, and the elemental carbon to organic carbon ratio for 11 different types of combustible materials. Figure 3 (page 4) shows the total carbonyls for these same materials. Results from a previous study that measured CO and CO_2 emissions for CCA treated pine are included as a reference in figure 1.

FIGURE 1: EMISSION FACTORS (MEAN + STANDARD DEVIATION) OF CARBON MONOXIDE (CO), CARBON DIOXIDE (CO_2) AND TOTAL CARBONYLS



Carbon monoxide

The highest emission factors of CO were observed for polystyrene, followed by plasterboard, particleboard with melamine and polyester. In comparison, pine recorded the lowest emission factors.

Fine particulate matter

The highest emission factors of fine particulate matter were measured for polyester and polystyrene (figure 2, page 3). Both materials emitted approximately 20 times more particles compared to pine, while carpet emitted approximately nine times more particulate matter than pine. No major differences were observed among wood-based products.

Elemental carbon and organic carbon

Wood-based materials were found to have the lowest carbon emissions, while polyester, carpet and polystyrene had the highest (figure 2, page 3).

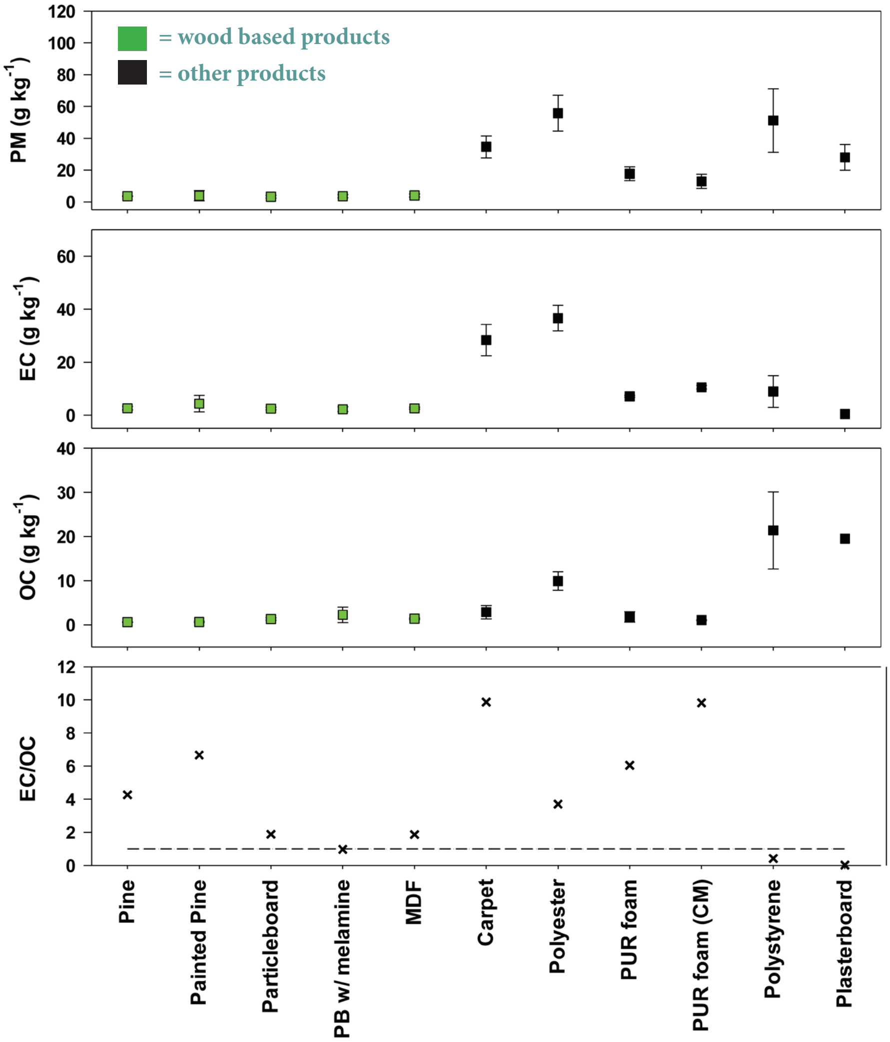
In general there was a larger fraction of elemental carbon compared to organic carbon. The exception was with polystyrene and plasterboard, where a significant organic carbon fraction was recorded. Lower

END USER STATEMENT

The research undertaken into smoke toxins in the rural/urban interface sets a sound foundation for the future, helping to inform both firefighting practices and equipment. There is little peer-reviewed research into actual toxins in the smoke at rural/urban interface fires. There is even less research about the actual levels of exposure to toxins that firefighters encounter in the course of their work. Once fire agencies have information about the actual exposures and their likely spread at rural/urban interface fires, agencies will be better placed to deploy firefighters more safely, as well as provide advice to the community, enabling them to better protect themselves from the hazards of smoke.

– Robyn Pearce, Director Human Services, Tasmania Fire Service

FIGURE 2: EMISSION FACTORS (MEAN + STANDARD DEVIATION) OF PARTICUALTE MATTER (PM), ELEMENTAL CARBON (EC), ORGANIC CARBON (OC) AND EC/OC MEAN RATIO



elemental carbon to organic carbon ratios were also observed for manufactured wood-products when compared with pine, with the difference likely due to the presence of glues and resins in the manufactured products. The organic fraction is likely to contain harmful organic compounds.

Carbonyls

Carbonyls, a class of irritating volatile compounds, were emitted at highest concentrations during combustion of polystyrene, with emission factors for total carbonyls being 45 times higher than those for pine. Other materials with high emissions of carbonyls were plasterboard, polyester and polyurethane foams.

The relative distribution of individual carbonyls for each material is shown in Figure 3. It clearly shows, with the exception of polystyrene, that formaldehyde and acetaldehyde were the dominant carbonyls, contributing 29-93% to the total emissions of carbonyls. Formaldehyde is a known human nasal carcinogen, while acetaldehyde is a possible human carcinogen. For the combustion modified polyurethane foam, acetaldehyde was the dominant carbonyl (80%). Both polystyrene and carpet had significant emissions of the strong irritant benzaldehyde. Acrolein, another strong irritant, was emitted primarily during combustion of wood-based products. About two to four times the amount of emissions were observed for manufactured wood products compared to pine.

▲ The study assessed emissions in smoke when houses, sheds and objects commonly found around the home are burnt.

A wide range of volatile organic compounds were identified during testing. These can have health effects that range from irritation of the eyes, skin, nose, throat and respiratory system, to headaches, dizziness, drowsiness and nausea, to being possible and known human carcinogens. While a number of volatile organic compounds (benzene, toluene, styrene, xylenes, naphthalene, acetic acid and phenol) were present during combustion of all materials, others have only been identified during combustion of specific materials. These include pyrrole and nitriles, which were emitted during combustion of nitrogen-containing materials only (particleboard, medium-density fibreboard, carpet) and pinene, camphene and limonene, which were emitted solely from combustion of wood-based materials. In general burning wood-based and polymeric materials released volatile organic compounds at higher concentrations than pine. As a result, the combustion of these products in fires at the rural/urban interface is likely to present a greater health risk than forest bushfires.

REFERENCES/FURTHER READING

Reisen F, 2011a, Inventory of major materials present in and around houses and their combustion emission products, Bushfire CRC, East Melbourne.

Reisen F, 2011b, Toxic emissions from fires at the rural/urban interface – desktop study, Bushfire CRC, East Melbourne.

Leonard J, Bowditch P, Dowling V, 2000, Development of a controlled-atmosphere cone calorimeter, 24(3), *Fire and Materials,* 143-150.

HOW COULD THE RESEARCH BE USED?

The research will provide a better understanding of exposure risks to personnel and communities during bushfires that extend into the rural/urban interface.

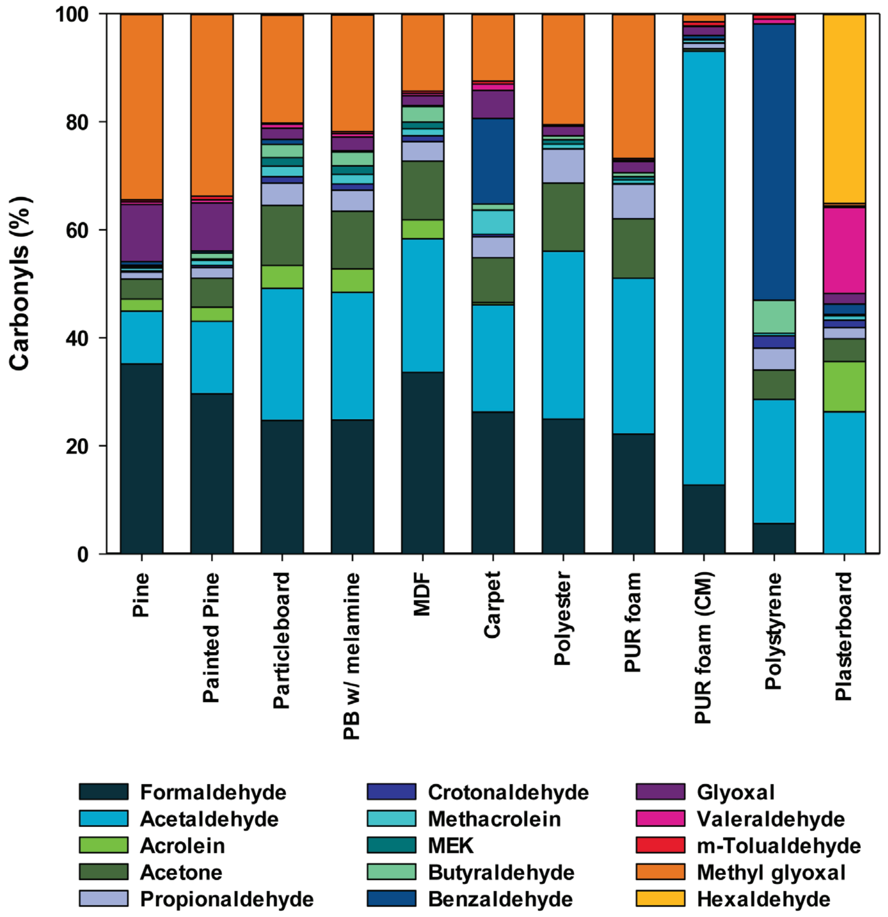
The emphasis for assessing this exposure risk (see breakout box, bottom right) is on inhalation – exposures that occur outside of burning structures at varying distances from the emission source and the smoke plume. It is assumed that in most cases firefighters do not wear breathing apparatus and that the majority of firefighting will be done outdoors. This clearly distinguishes firefighting at the rural/urban interface from firefighting at structural fires.

The outcomes from the research can be used to inform training, work practices and appropriate use of personal respiratory protective equipment, as well as to assess the use of truck-mounted air monitoring devices and to provide advice on firefighter and community safety.

FUTURE DIRECTIONS

The emission factors determined during the small-scale experimental burns described in this *Fire Note* are not necessarily representative of all exposures firefighters could encounter. However, they do provide an important input into a high time-resolution dispersion model that will provide short-term modelled ground concentrations, resulting in a reliable estimate of potentially hazardous exposures. Significant additional work is required to develop a useable set of scenarios and compare modelled exposure concentrations to previously measured exposures at structural fire incidents. Monitoring was conducted at structural training fires which simulated room fires in three typical rooms (living room, bedroom and office). The results will provide data to validate outputs from the model.

FIGURE 3: RELATIVE DISTRIBUTION OF INDIVIDUAL CARBONYLS EMITTED DURING COMBUSTION OF VARIOUS BUILDING AND FURNISHING MATERIALS



ASSESSING EXPOSURES

Exposures are assessed against occupational exposure standards, presented as either peak or ceiling limits, short term limits or time-weighted average limits. If only one toxin is present, there is an unacceptable level of risk if the hazard quotient (the ratio between the exposure concentration and the respective occupational exposure standards) is greater than one. For toxins that target the same part of the body (i.e. lungs, eyes), hazard indices assess exposure limits. A hazard index is the sum of the hazard quotients of all toxins that target the same area of the body. Any hazard index of more than one is an unacceptable level of exposure risk.

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Bushfire Cooperative Research Centre
Level 5/340 Albert Street
East Melbourne VIC 3002
Telephone: 03 9412 9600
www.bushfirecrc.com

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Australasian Fire and Emergency Service Authorities Council
Level 5/340 Albert Street
East Melbourne VIC 3002
Telephone: 03 9419 2388
www.afac.com.au

AFAC is the peak representative body for fire, emergency services and land management agencies in the Australasia region. It was established in 1993 and has 35 full and 10 affiliate member organisations.