EXECUTIVE SUMMARY

While much research has been conducted regarding the cost of fire in terms of human life, property loss and business interruption, relatively little research has been conducted on the impact of fire on the natural environment. However, this topic is gaining new attention with global concerns associated with the impact on climate change resulting from carbon emissions: a by-product of most fires. In addition to carbon emissions, impacts can include non-carbon contamination of the air via the fire plume, contamination of soil and water from the deposition of products of combustion in the fire plume, contamination from firefighting water runoff containing toxic products, and other such environmental discharges or releases resulting from burned materials or otherwise released as a result of fire. This effort reviews existing research on the environmental impact of fire, including sources of contamination and associated effects, approaches to quantifying the impacts in terms of hazards, risks and cost – at a local level and at a regional level, identifies gaps in knowledge that are needed in order to make better assessments of the environmental impact of fire, and provides a conceptual framework for undertaking more comprehensive impact assessments once the needed data and information are available.

A review of literature related to environmental impact of fire was undertaken. As a starting point, the review considered sources two main themes:

a) Determining how 'environmental impacts' from fire is defined. This was needed to develop a working definition, or set of boundary conditions, for 'environmental impacts' of fire as related to the scope of this project. This was necessary to help better define the environmental impacts of concern, as well as to provide a basis for comparative analysis of the different environmental impact assessment methods used.

b) Review of fires with severe environmental effects. There have been several fires in recent history that have gained infamy because of their adverse environmental impacts. Identifying these fires provided examples as to the severity of impact from single fire events. The fires also offered the opportunity to see a documented approach to assessing the adverse impacts to the environment.

From this starting point, several sub-topic areas were identified as needing further study, including:

c) Identifying hazardous products from a fire.

d) Analytical techniques to quantify the environmental effects of fire

e) Transmission pathways for environmental stressors (hazards) to attack receptors (targets).

For the initial phase of this project we undertook a broad international literature search to gain an understanding of the work which has been previously conducted in the topic area. Currently the collection of source material has grown to more than 150 references, consisting of research papers, studies, and books. Appendix D: Bibliography of Relevant Literature contains the full bibliography.

From these sources, a smaller selection of documents was chosen for more detailed review. These were selected by filtering our bibliography by keyword, author, and organization. The sources whose title contained `impact assessment' were chosen, especially if they also referred to fire. Sources whose title also mentioned quantified data were also reviewed more closely. Lastly sources that looked at a specific type of analysis were also selected. *Appendix C: Review of Selected References* , contains the more detailed literature summary. The review includes the following topical areas.

 Fire statistics, which provide a picture of the fire problem. These were gathered from such sources as the NFPA, International Association of Fire and Rescue Service (CTIF), The Geneva Association, as

well as from a number of countries {Australia, Canada, Germany, Ireland, New Zealand, South Korea, UK, USA}.

 Impact assessment studies, which have been conducted for fires that have caused environmental damage. These include such events as the Sandoz fire and chemical spill in Basel, Switzerland, and the Sherwin William Paint Warehouse fire in Dayton, Ohio (USFA, 1987).

 Studies associated with sustainability and fire protection. FM Global (FM Global, 2010) completed a study showing the sustainability of sprinkler systems in residential buildings both in terms of water savings and limiting the effects of a fire. A similar study from BRE compared, using a life-cycle analysis, what the cost savings of installing and maintaining sprinklers is for small, medium, and large scale warehouses. Additionally, BRANZ considered what is important for sustainable construction, considering fire, and different techniques to limit the growth and spread of fire

 Research studies and papers on wildland fires and the environmental impacts that result. Wildland fires produce small particulates that can be very damaging to humans, especially those with any lung related health problems. Wildland fires are extensively studied not only for their immediate effects, but their long-term effects as well. Effects of burning out a portion of the forest range from increased erosion and problems for water quality to habitat degradation.

 Different techniques for quantifying the impact of fire from different products, with and without fire retardants. One of the most prominent is the "Fire-LCA", developed by SP in Sweden in the early 2000s (Andersson, et al., 2004). Hamzi et al. (2008) have done a significant amount of research to look at different products and quantify what the life cycle costs of the product would be if the product was to be impacted by a fire at any point over its life.

 Standards and guidelines. Of particular interest is the ISO Standard 26367, *Guidelines for Assessing the Adverse Environmental Impact of Fire Eff luents*. ISO 26367 Part 1, a published standard, providing an overview of the subject area, including describing fire effluents, what the environmental impacts of the fire effluents are, how intervention can be considered, and how to assess the overall environmental impact. ISO 26367 Part 2, currently at the Committee Document stage (unpublished and not publically available), will likely include details on toxic products of combustion and means to sample them in-situ, when published.

There are several limitations and bounding conditions associated with this study.

 One aim of this study was to investigate different approaches that have been undertaken for environmental impact analysis in other fields and whether they can be used to assess the impact of fire. To appropriately address the topic it was determined that it would be necessary to provide some discussion on the different ways that "environment" and "impacts" are defined. There are also several different reasons for conducting an environmental impact assessment.

 Another aim was to identify what types of impacts can be quantified as well as how they are quantified. It was found that there is often consideration of a wide range of impacts to a diverse biological spectrum, including people. It was also found that quantification can be local or global, species or system related, and narrowly or broadly encompassing. After initial investigation of the problem and discussion with the Project Panel, the scope was limited to ecological impact assessments, with human health impacts deemed out of scope. Also, while the topic of calculating the environmental impact of fire was identified as important, this effort describes how to go about quantifying the impacts, but does not include an explicit calculation method or examples.

 The types of materials produced during fires depend in large part on what is burning (e.g., vehicles, buildings and contents, vegetation). These materials are introduced to the environment through

several pathways through the air, water and soil. This is needed to identify compounds and materials which could have an impact to the environment.

- Although fires occur in buildings of all sizes, in nature, and in vehicles, it was decided to limit the research to wildland fires and to buildings of different use and scale, from residential occupancies to industrial facilities, with a particular emphasis on individual building / facility impact and not aggregate impacts (in the first instance), recognizing that there are challenges associated with contents of buildings, which are not always regulated by code and therefore the extent of impact not easy to determine (within the scope of this effort).
- With respect to buildings there are two aspects to the problem. The first is the combination of the building materials and contents, which have changed over time to include more synthetic plastic and textile materials (Kerber, 2010). The newer materials prove to be more flammable and toxic than natural materials. The second aspect is the addition of flame retardants to try to reduce the flammability of the contents. In recent years there have been several studies on the use of fire retardants. This research paper, in particular, did not include the effects of contents or fire retardants in its scope.
- Ultimately, it would be of interest to investigate not only the environmental impact of individual fires but how different sectors impact the environment in aggregate: locally, regionally and globally. In concept, one starts with assessment of a fire that occurs at a certain locality and scale. Once the fire occurs the environmental effects are measured in terms of the effect on the air, ground, and water. The effects are evaluated using expert systems. The evaluation of the effects is then used to determine the environmental impact in terms of ecology, environmental pollution, esthetics, and human interest. This can then be scaled for regional or other-scale effects by aggregating the impacts. While this effort does not get to this aggregate view, a potential path is provided.

This research has identified that a significant amount of information is available regarding the environment and the fire effects. However, the information is not complete, nor are the means to utilize that information in decision making. The following gaps have been identified, where additional knowledge and information could be researched in more depth and made available for decision makers.

1. Reporting/Study post fire event

From the beginning of the report several high profile fires with adverse environmental effects were described. For those fires, some information was able to be tracked down, but it was surprising how difficult it was. For most other fires, where concern for the environment was not considered there is little information. A reporting mechanism for fire departments to provide any feedback regarding the risk management of the fire during the event should be explored.

2. Process for EIA during construction

It is becoming common place for buildings to be constructed with some level of certification as to their sustainability, namely LEED in the United States. The building codes are catching up to this level of energy efficiency. It is recommended that an environmental impact assessment (EIA), which includes a fire event, be conducted.

3. Risk assessment tools for fire departments

There are some fire events which did have good environmental risk assessment done by the incident command, however there were also some fire events where better defined risk management techniques would have provided better guidance for the incident commanders. New tools and methods should be explored that provide fire departments with a clearer direction about which intervention technique(s) would be the most beneficial.

4. Exploring the impact of building contents

The contents of a building can change from year to year or even hour to hour depending on the occupancy. The contents of a building can make a difference when choosing a design fire for a space and it is seemingly similar for an environmental impact study. For example a large warehouse filled with bricks would be very different than a warehouse filled with fertilizer, herbicide, and other pesticides both in terms of the fire and that the environmental impacts would result. It is recommended that some sensitivity studies be conducted to determine the effect of contents beyond the studies from FM Global and BRE.

5. Exploring the impact of fire retardants

As building contents change to be more susceptible to fire, new fire retardants are being created to challenge the fire ignition and initial growth. It is recommended that a database of fire retardants and the products of combustion, when they are burned, is created to more fully understand their hazard and toxicity.

6. Detailed fire information for global fire problem

NFPA provides good records for the fire problem in the United States, as do many other countries, but it is difficult to find information regarding fires for the entire world. With the advance of sustainable design and rigid guidelines being developed there should be additional detailed records kept about the fire. The record keeping of fire events in other countries is most likely a political issue as well as a logistical issue, regardless options for expanding fire and environmental impact events should be explored.

In the end, this effort identified, summarized and compiled a large database of resources which help to define issues associated with characterizing the environmental impacts of fire. The outcomes of this effort can provide solid foundation for additional research in this area. The following outlines future research which could be of benefit in this area. Three major areas for future research are suggested, each aimed at providing environmental impact assessment tools for different stakeholder groups:

1. Decision tool for first responders

i) Quantified information about hazards

ii) Quantified information about contents

iii) Quantified information about fire extinguishing materials

iv) Risk management framework for quick/Easy analysis

v) Methodologies to report environmental impacts of fires

vi) Survey to determine, whether and to what extent first responders consider environmental impacts of fire

2. Decision tools for designers

i) Quantified information regarding hazards

ii) Tool describing differences of the environmental effects of one product undergoing combustion versus another product

iii) Survey to determine, whether and to what extent designers consider environmental impacts of fire

iv) Development of a decision tool incorporating quantified analysis techniques (LCA, CBA, RA) to compare the levels of fire protection at the design stage

3. Decision tool for policy makers

i) Information regarding aggregate fire problem

ii) Methods of gathering necessary data from the international community

iii) Comparative study of existing global regulatory frameworks

iv) Study to identify paths to incorporating fire in environmental policy

v) Survey to determine, whether and to what extent policy makers consider environmental impacts of fire
vi) Development of a decision tool incorporating quantified analysis techniques (LCA, CBA, RA) to compare the levels of fire protection at the building code/policy level

Prioritization of these efforts will depend on the goals and objectives of the responsible stakeholder groups. If the goal is to improve the environmental impact from first responders and the fire service then number one (1) should be undertaken to understand more fully the environmental impacts that the fire service contributes when attacking a fire and what possible changes they can make to reduce their environmental impact. Similarly fire protection designers can make a number of choices that affect the environmental impact of a building when considering if a fire does occur. There are numerous tools that exist to calculate the environmental footprint of a building and similar techniques could be used to account for the effects of fire. Number two (2) would involve exploring ways to incorporate the comparable sustainability between different types of fire protection measures. This could help answer questions as to what extent should sprinklers be implemented versus structural fire protection. The decision tool for policy makers described in number three (3) could be developed to understand the fire problem from a holistic viewpoint including the use of fire protection (preventive) and fire intervention (attack). To accomplish this an agreed way to calculate the aggregate effects of the fire would need to be established. A large concern with doing this currently is the lack of equivalent data from country to country. Another concern that needs to be addressed is which impacts are considered important and how to rank impacts that effect different parts of the environment, for different periods of time. If these can be resolved it is recommended that we determine an aggregate data set for comparison to other sources of environmental impacts as well as to get an accurate picture of the problem. Then ways to better incorporate prevention and intervention techniques could be implemented from a policy point of view.