Executive summary

It is recognized from past experience that fire spread from floor to floor and over the façade in buildings can be a catastrophic event. The regulatory and test based methodology to address behaviour of fires in facades for different facade systems varies significantly for different countries. One difficulty is that several materials and assemblies are involved such as Timber, Plastics, GRP, Glazing, Polymeric composites, Cement based products, with and without insulation. The other difficulty is that there is not a consensus to select the size of exposure fire for testing and evaluation of any given facade system. The fire hazard is more severe if components of the facade assembly are combustible. Some past fire incidents have demonstrated rapid and extensive fire spread over the length of the façade either externally or internally through the insulation cavity. For facades with no combustible components, fire spread may occur from floor to floor in a leap frogging fashion.

Phase I of this study seeks and is structured to collect data about combustible facade systems, review existing research in this area, examine statistics on façade fires, list incident of facade fires, describe the mechanisms and dynamics of fire spread, review existing test methods and performance criteria, and conclude with recommendations for a testing approach and methodology for a possible future experimental research Phase II.

This report has been prepared by CSIRO and FireSERT (university of Ulster) for the Fire Protection Research Foundation (FPRF) as the deliverable for the project *Fire Hazards of Exterior Wall Assemblies Containing Combustible Components –Phase I.* This phase investigated the following items:

- Combustible exterior wall systems in common use
- Existing Research and mechanisms of fire spread
- Fire Statistics
- Fire Incident Case-Studies
- Test Methods and regulations

Types of combustible exterior wall systems in common use include:

- Exterior Insulation Finish Systems (EIFS, ETICS or synthetic stucco)
- Metal composite material cladding (MCM)
- High-pressure laminates
- Structural Insulation Panel Systems (SIPS) and insulated sandwich panel systems
- Rain screen cladding or ventilated facades (curtain walls)
- Weather-resistive barriers (WRB).
- External timber panelling.

These exterior wall systems are typically complex assemblies of different material types and layers which may include insulation layers and vertical cavities, with or without fire stopping.

A brief overview of existing research related to fire performance of exterior combustible walls is provided. The Fire Code Reform Centre funded a research report on fire performance of exterior claddings[1] provides an excellent overview of the previous research up to the year 2000. Appendix D of this report also provides a list of related research literature for further reading.

The key initiating fire can be one of two possible types of fires:

I. Fires external to the building (other burning buildings, external ground fires) or
II. Fires internal to the building originating in a floor that have resulted in breaking the windows and ejecting flames on the façade

Key mechanisms of fire spread after initiating event include:

I. Fire spread to the interior of level above via openings such as windows causing secondary interior fires on levels above resulting in level to level fire spread (leap frogging)
II. Flame spread over the external surface of the wall if combustible.
III. Flame spread within an interval vertical cavity /air gap or internal insulation layer. This may include possible failure of any fire barriers if present, particularly at the junction of the floor with the external wall.
IV. Heat flux impacts causing degradation/separation of non-combustible external skin (loss of integrity) resulting on flame spread on internal core
V. Secondary external fires to lower (ground) levels arising from falling burning debris or downward fire spread.

It follows from this research review that the façade fire safety problem can be divided into four parts:

1. Specification of fire exposure scenario and the heat flux distribution both inside the enclosure and from the façade flames originating from the fire in the enclosure. This requirement is prerequisite for the following parts.
2. Fire resistance of the façade assembly and façade-floor slab junction including structural failure for non-combustible and combustible façade assemblies.
3. Fire spread on the external surface of the façade assembly if combustible due to the flames from the enclosure fire.
4. Fire spread and propagation inside the façade insulation, if combustible, due to the enclosure fire.

Statistics relating to exterior wall fires from the USA, Australia and New Zealand and Nordic countries have been reviewed. Statistical data relating to exterior wall fires is very limited and does not capture information such as the type of exterior wall material involved, the extent of fire spread, or the mechanism of fire spread. Exterior wall fires appear to account for somewhere between 1.3% and 3% of the total structure fires for all selected property types investigated. However for some individual property types exterior wall fires appear to account for a higher proportion of the structure fires, the highest being 10% for storage type properties. . This indicates that exterior wall fires are generally low frequency events, particularly compared to fires involving predominantly the interior. The statistics also indicate that sprinkler systems are likely to have an effect on the risk of exterior wall fires by reducing the risk of spread from an internal fire to the exterior façade. However a significant portion of external wall fires still occur in sprinkler protected buildings, which may be due to both external fire sources and/or failure of sprinklers. On this basis it is recommended that controls on flammability of exterior wall assemblies should be the same for sprinkler protected and non-sprinkler protected buildings.

Fire incidents involving exterior wall assemblies around the world have been reviewed. This review indicates that although exterior wall fires are low frequency events, the resulting consequences in terms of extent of fire spread and property loss can be potentially very high. For most of the incidents reviewed the impact on life safety in terms of deaths has been relatively low with the main impacts being due to smoke exposure rather than direct flame or heat exposure. However a large number of occupants are usually displaced for significant periods after the fire incidents. This has particularly been the case for incidents in countries with poor (or no) regulatory controls on combustible exterior walls or where construction has not been accordance with regulatory controls. Combustible exterior wall systems may present an increased fire hazard during installation and construction prior to complete finishing and protection of the systems. The 2009 CCTV Tower Fire and 2010 Shanghai fire in China are examples of large fires occurring during construction.

Regulation and building code requirements for fire performance of exterior wall assemblies around the world have been reviewed. Five aspects of regulation have been identified to influence the risk of fire spread on exterior wall systems. These include reaction to fire of exterior wall systems and individual components, fire stopping of cavities and gaps, separation of buildings, separation of openings vertically between stories of fire compartments and sprinkler protection. Of these, the reaction to fire regulation requirements are expected to have the most significant impact on actual fire performance and level of fire risk presented by exterior wall assemblies. Countries such as the USA, UK, and some European countries specify full-scale façade testing but then permit exemptions for specific types of material based on small-scale fire testing. The United Arab Emirates has recently drafted and is applying regulations using full scale façade testing combined with small scale tests in response to a spate of fire incidents involving metal clad materials in 2011-2012. New Zealand primarily applies the cone calorimeter ISO 5660 for regulation of exterior walls. This appears to be the only country to do this. Some countries including Australia have no reaction to fire requirements except that the exterior walls must be non-combustible. However in practice combustible systems are applied as fire engineered performance based designs (Alternative Solutions). In some countries fire resistance tests are also required.

A range of different full-scale façade tests are in use around the world and have been reviewed for this report. The geometry, fire source, specimen support details, severity of exposure and acceptance criteria varies significantly for different tests. Existing research has identified that exposure to the exterior wall system is generally more severe for an internal post flashover fire with flames ejecting from windows than for an external fire source. For this reason, almost all of the full scale façade fire tests simulate an internal post flashover fire. However it is possible for the severity external fires at ground level on fuel loads such as back of house storage areas and large vehicle fires to equal or exceed internal post flashover fires. Although most full-scale façade tests simulate an internal post flashover fire they may also set a suitable level of performance with regards to external fires.

Full-scale façade tests are currently the only method available for absolutely determining the fire performance of complete assemblies which can be influenced by factors which may not be adequately tested in small scale tests. These factors include the severity of fire exposure, interaction of multiple layers of different types of materials, cavities, fire stopping, thermal expansion, fixings and joints. However full-scale tests are usually very expensive. Based on the present review we note that:

- Dimensions and physical arrangement of facade tests vary. As an example, some large-scale tests involve external corner walls 8 meters high (UK) or 5.7 m high (Germany and ISO) and 2.4 m and 1.3 m wide
- There are significant differences in the source fire simulating a fire in the room of origin. Wood cribs, liquid pool fires and gas burners are being used to generate maximum heat fluxes on the façade in the range of 20 to 90 kW/m^2. It needs to be investigated if these fires represent a sufficient and reasonable exposure to represent real fire scenarios.
- Test durations, measurements and acceptance criteria vary.
- The degree to which suitability of fixing systems and fire spread through joints, voids and window assemblies of a multifunctional façade assembly are tested varies.
- Whilst large-scale facade tests do not measure key flammability properties of the individual elements of the facades, these tests do provide useful information for validation of fire spread modelling.

Intermediate-scale tests including ISO 13785 Part 2, the Vertical channel test and also a variety of room corner tests have been reviewed. These are less expensive however they may not correctly predict real-scale fire behaviour for all types of materials due to less severe fire exposures, less expanse of surface material to support fire growth and flame spread, and less incorporation of end use construction such as joints, fire stopping and fixings etc. Except for the SBI test, intermediate scale tests are currently not used for regulation however they are a cost effective method for product development. The SBI test is currently typically applied to individual façade components rather than whole assemblies

Small scale tests applied for regulation of exterior wall materials around the world have been reviewed. Small scale tests often are only applied to individual component materials and represent very specific fire exposure conditions. Small scale tests can provide misleading results for materials which are complex composites or assemblies. This is particularly the case where a combustible core material may be covered by a non-combustible or low-combustible material or a highly reflective surface. There is currently no practical method of predicting real scale fire performance from small-scale tests for the broad range of exterior wall systems in common use. Small scale tests may provide acceptable benchmarks for individual material components. However further validation against full-scale tests may be required to support this. Small scale tests (in particular the cone calorimeter) can also be useful for doing quality control tests on materials for systems already tested in full-scale or for determining key flammability properties for research and development of fire spread models. Small scale tests, such as the cone calorimeter should not be used to assess the performance of the whole façade assembly.

Development of a new full-scale test to simulate a specific fire scenario is not recommended at this stage. Instead further research to validate the existing full-scale and small scale tests and also to develop a more affordable and dependable intermediate-scale test are recommended. A range of options for further test based research for Phase II have been proposed. In summary, these are:

- Option 1 – Existing Full scale façade test round robin – conduct tests on the same wall assembly applying the different large scale tests currently operated by labs around the world. This would increase understanding of the relative performance of the different test method, provide a basis for accepting systems tested under different methods and would provide full scale data to support other research options suggested.
- Option 2 – Development and validation of intermediate scale façade test – This may possibly enable reliable regulation of materials using a less expensive test or, at least enable less expensive testing for product development.
- Option 3 – Validation of small scale test regulatory requirements against large scale tests. This would include collating any exiting small-scale and full-scale test data on a range of exterior wall systems that can suitably be applied to validate requirements. Indentify and carry out any further small-scale and full-scale testing that may be required to validate requirements. Examine test data to investigate any correlations and limitation of small scale tests vs. large scale performance and conclude on the suitability of existing regulatory requirements. Investigate more appropriate ways to test individual façade components which in combination with proper fire breaks would give a better assessment of the behaviour of a full-scale façade
- Option 4 – Investigation of vertical “U” channel on full scale test –Fire incidents indicate that very rapid fire spread may result for external vertical “U” shaped channels extending over a significant height of the building created by balconies and the like on the exterior. Modifying an existing full-scale test would enable investigation the impact this profile has on materials which pass in standard test geometry and if any increased requirements are needed for materials that are to be installed in this arrangement in end use. Assessment of this situation and the development of such a test (“U” Shaped façade with side wing walls) may be assisted by the recent work by FireSERT and USTC (China) on facade flame heights with side walls[2].
- Option 5 – Development of façade flame spread models - Continued research on developing and validating flame spread models is required to move beyond current limitations.

An alternative or parallel performance based approach, which can also be used for risk analysis, is also proposed:

1. Assess and Measure key flammability properties of the combustible facade components in small (cone calorimeter) and intermediate scale experiments (SBI). Based on these tests and analysis,

classify, for example, the materials according to European regulations for construction products. Then for regulation, Euro class B or better may be accepted for individual components.

2. Determine size of fire for the specific enclosure in the built environment based on recent research work.
3. Reproduce this fire size using a gas burner in a test similar, for example, to one proposed and developed in Japan as option 2.
4. Measure and / or model the heat fluxes of facade flames on an inert façade in the selected test
5. Test the real facade assembly and use the results to assist in establishing regulations
6. If load bearing facade, perform also a fire resistance test with conditions reproducing the heat fluxes in part 3.