

# **ETANKFIRE**

**Ethanol Storage Tank Fire Protection - Description of Work**

**Phase 1**

2012-03-07

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# 1 Goal and background of the ETANKFIRE project

The main goal of the ETANKFIRE project is to provide a platform of knowledge ensuring proper investment in the fire protection of ethanol storage facilities. This will involve understanding large scale burning behaviour and developing and validating a methodology for fighting fires in tanks containing ethanol fuels. In order to achieve this goal, it will be important to provide an understanding of the differences between conventional fire fighting of spill fires versus tank fires containing water miscible fuel products.

The use of ethanol has increased significantly as a means to fulfil climate goals by replacing fossil fuels with renewable fuels. However, the introduction of ethanol fuels creates new risks and challenges from a fire protection point of view.

Although tank fires in general are rare, and the number of ethanol tank fires to date is very few, extensive fire protection measures will be required based on various national laws and regulations. Typically this translates into significant investments, both in preventative measures and risk mitigation measures including extinguishment in the case of a full scale fire. However, as practical experience is very limited and the standards for fire protection often lack specific information concerning ethanol and similar fuels, there is a great risk that such investments will not provide the fire protection level expected.

Some test data on foam fire fighting of ethanol fuels and other water miscible products are available, even in reasonably large scale, but all such data relates to spill fire scenarios, i.e., relatively thin fuel layers. Similarly, existing test standards for alcohol resistant foam concentrates (ISO 7203-3, EN 1568-4, UL162, etc.) all employ thin fuel layers and short pre-burn times and therefore also represent spill fires. Even spill fires will create fire fighting problems and the conclusion from various large scale tests and standard test methods is that the use of alcohol resistant (AR) foams is a fundamental requirement to obtain extinguishment of water miscible fuels. However, the tests have also shown that AR foams will fail unless gentle (Type I or II) foam application onto the burning fuel surface can be achieved. So far, no alcohol resistant foam has passed any of the mentioned standard test methods using forceful (Type III) application.

As storage tank fires are usually extinguished using large capacity foam monitors, the requirement for gentle (Type I or II) application will be very difficult to fulfil and in practice, extinguishment cannot therefore be expected. The current general industry advice for tank fires is to direct the foam stream against the inner side of the tank wall but this is not always possible to achieve in practice and is an unproven method in real scale situations. A tank fire will also present a more severe situation compared to a spill fire due to the large fuel depth and consequently the dilution effect from fire fighting foam will be limited in a short term perspective. In most situations, the pre-burn time will also be longer than that expected in a spill fire scenario, thereby increasing the temperature of the fuel and creating hot steel surfaces, making extinguishment even more difficult. It is, therefore, important to provide an understanding of the differences between conventional fire fighting of spill fires versus tank fires containing water miscible fuel products and to develop and verify a suitable fire fighting methodology to ensure reliable fire protection of ethanol storage tanks.

A very important and related issue is that the burning behaviour of a large scale ethanol fire may be significantly different from that of a petroleum fire. Tests with similar fuels indicate that the radiated heat of an ethanol fire could be significantly higher than that of a gasoline fire, which increases the risks for fire escalation. Experimental data is needed to fully

understand the risks associated with large scale ethanol fires and our present fire fighting capabilities. Such data could be used to validate computer models, thereby improving our ability to make reliable risk assessments without full scale testing in the future.

## 2 Project structure

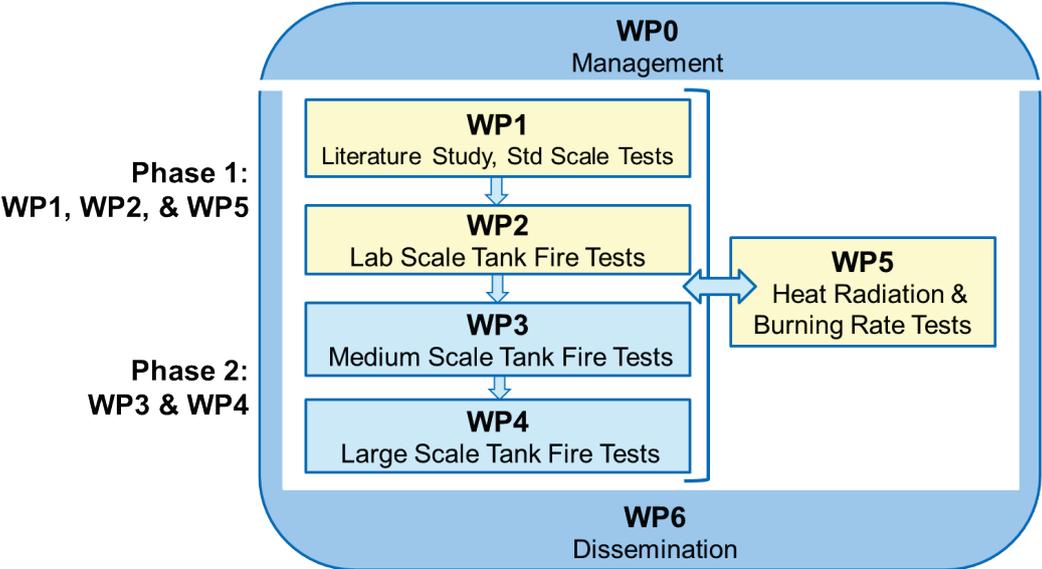
The overall structure of the project is shown in Figure 1 which has been designed to provide a small but effective organisation to manage the project and continuously evaluate the experimental results as a basis for subsequent test planning. This will ensure that the results of the project are rapidly collated and disseminated to the involved industry, authorities, etc.

The ETANKFIRE project is structured into seven work packages (WP0 to WP6) as shown in Figure 1. The work in WP1 to WP4 will be related to the extinguishment of ethanol storage tank fires while work related to burning behaviour will be handled in WP5.

The project will be conducted in two phases:

**Phase 1** will focus on WP1, WP2 and WP5 and the amount of work in each WP will depend on available funding. The work described below is based on a tentative budget which assumes a funding level of about 500 k€, corresponding to at least 10 Full Partners, see Section 5.

**Phase 2** will be conducted after Phase 1 is completed and will include the suggested medium and large scale tests in WP3 and WP4, as these tests will require substantial resources and therefore also additional funding. Detailed planning of these tests is not possible to do prior to the completion of Phase 1 as it will be based on the work and results obtained in Phase 1. However, to give an indication of the plans for Phase 2, the suggested preliminary content of WP 3 and WP4 is described in an annex to this document.



**Figure 1.** ETANKFIRE project structure where Phase 1 will involve WP1, WP2 and WP5 and Phase 2 will focus on WP3 and WP4. The activities in WP0 and WP6 will be included in both Phase 1 and Phase 2.

### 3 Work description for Phase 1

Below is a description of the work that will be included in Phase 1 of the ETANKFIRE project, involving technical work in WP1, WP2 and WP5. WP1 and WP2 are mostly focused on laboratory scale investigations of extinguishment of ethanol fires. WP5 involves free-burning tests of ethanol in both laboratory and large scale to study the burning behaviour of ethanol. This work will be supported by relevant management activities in WP0 and dissemination of the results in WP6, which are described in the ETANKFIRE Rules<sup>1</sup> and the ETANKFIRE Consortium Agreement<sup>2</sup>.

The proposed content of each work package is described in more detail below. The tests listed in each work package should at this stage be considered as a proposal from the Research and Testing Group (RT Group) for the experimental work in order to balance the assumed total budget for Phase 1. The final planning and number of tests will be decided in cooperation with the ETANKFIRE Steering Committee (SC) and will also depend on the number of Consortium Partners and available funding. This work description will therefore need to be updated as the project proceeds.

#### 3.1 Work Package 0: Project management

The project will be managed by SP Technical Research Institute of Sweden (SP) in close collaboration with Resource Protection International (RPI). SP will be responsible for management of the ETANKFIRE project, for the detailed planning of the test programme, the experimental work in WP1, WP2 and WP5, and for the evaluation of test data under the guidance of the SC. RPI will chair the SC and GA meetings and be responsible for dissemination of project results in WP6. Information about the roles of the SC and other project participants is found in the ETANKFIRE Rules.

**Table 1. Work Package 0 - Management.**

<b>Time schedule:</b>	M0-M24
<b>Objectives:</b> To administer, monitor, plan and facilitate <i>ETANKFIRE</i> to ensure that the project's stated objectives are delivered on time and within budget.	
<b>Description of work:</b> The ETANKFIRE project management will be performed by SP, who will assign a suitably qualified project manager. The project manager's responsibilities will encompass: <ul style="list-style-type: none"><li>• Overall coordination of the project.</li><li>• Update of project progress indicators (Gantt chart, deliverable/milestone status, budget, etc.).</li><li>• Organisation and documentation of meetings.</li><li>• Document control.</li><li>• Formal reporting to the SC. In addition to technical reports at the completion of each work package, progress reports will also be submitted to the SC at each regular meeting.</li><li>• Financial management.</li></ul>	

<sup>1</sup> ETANKFIRE Project – Rules for participation, 2012-03-07

<sup>2</sup> RTG – ETANKFIRE Consortium Agreement for the ETANKFIRE Project, 2012-03-07

- Preparation and maintenance of the project’s Consortium Agreement.
- Act as a central point of contact for partner queries regarding administrative, legal and financial matters.
- Act as a link between the Research and Testing (RT) Group, the SC, and the General Assembly (GA).

The project manager will be supported in the above activities by colleagues from SP’s “Grants and Contracts” and “Finance” Departments and by RPI.

**Deliverables:**

Management status reports for Phase 1 at each meeting, oversee the production of all technical reporting for Phase 1.

**3.2 Work Package 1: Literature Review & Standard Scale Tests**

WP1 will have a two-fold goal and form the basis for further detailed planning of WP2.

One part of WP1 will focus on a literature review in order to identify test data and experience from real tank fire incidents. Some test data, generally representing spill fire scenarios, has already been identified during initial project planning, but there might be significant work made by various public or private organisations that has either not been officially published or published in a native language making it difficult to identify on an international basis. It is also important to learn from real tank fire incidents involving ethanol or other water miscible fuels. At the present time, only a few fires have been identified in the open literature but more information is expected to be available if a more in-depth search is made by direct contacts with various oil and chemical companies, fire brigades, etc. In this work, a significant contribution from the ETANKFIRE Partners is also expected.

Another part of WP1 is intended to provide a connection to existing knowledge and standard performance requirements for fire fighting foams by conducting extinguishing tests in “standard scale”. The intention is also to provide a baseline of extinguishing performance for various ethanol fuel mixtures as guidance for the selection of fuel(s) for the tests in WP2.

The test programme in WP1 will also include some tests to study the influence of fuel depth and pre-burn time, respectively. In this case there will be a need for some minor changes of the fire tray to allow for additional fuel. Otherwise the standard procedures will be followed.

**Table 2. Work Package 1 - Literature Review & Standard Scale Tests.**

<b>Time schedule:</b>	M0-M12
<b>Objectives:</b> To identify test data and experience from real tank fire incidents and to provide a connection to existing knowledge and standard performance requirements for fire fighting foams applied to ethanol fuel fires. These test data will provide input data for the detailed planning of WP2.	
<b>Description of work:</b> A literature search will be performed to collect information about ethanol storage tank fires and their outcomes.  The experimental work will be performed by SP in collaboration with RPI as needed to conduct the fire tests listed below. This list is subject to revision by the RT Group and the SC. The test procedures proposed follow the foam standards ISO 7203-3 and EN 1568-4, which correspond to a 1.73 m <sup>2</sup> fire tray, 125 l of fuel and using UNI 86 test nozzles.	

1. Standard test on E95 (denatured ethanol with 3-5 % gasoline)
  2. Standard test on E85
  3. Test on E95 with 375 l of fuel (3 times standard quantity)-extended pre-burn time
  4. Test on E85 with 375 l of fuel (3 times standard quantity)-extended pre-burn time
- Some further tests could be valuable if funding/budget allow

**Deliverables:**

Report summarising the results and conclusions from the review of tank fire incidents and relevant tests. Technical report on findings of standard scale tests, fire suppression and fuel selection data to be used in WP2.

**3.3 Work Package 2: Laboratory Scale Tank Fire Tests**

The information from WP1 will be used to determine the test conditions in WP2, representing a small scale tank fire. It is proposed that these tests will be made in the same scale as in WP1 but that the test tray will be reconstructed to simulate a small scale tank, allowing a fuel depth of up to about 1 m and a pre-burn time of 15-30 min. The increase in the amount of fuel should ensure that the extinguishing effect due to dilution is minimised when using foam. The “tank wall” shall also be high enough to represent the more severe foam application conditions that could be expected in a tank fire situation. The preburn time should ensure steady state conditions to reasonably represent tank fire conditions.

The foam tests will include various foam application methods representing handlines and monitor application, fixed systems, medium expansion foam and Compressed Air Foam (CAF). Low expansion foam will be produced by using a UNI 86 test nozzle (if considered relevant) but there will also be a need for additional tests to study the influence on the foam application rate from using nozzles with similar foam properties but having higher flow rates. In addition to the use of foam, alternative extinguishing methods such as foam glass spheres and liquefied nitrogen will be considered as well, especially if various foam fire fighting methods are not found to be sufficient.

Although the dimensions of the tank will be limited and therefore not represent full scale conditions, the tests will provide performance results to allow the selection the most promising extinguishing methods for use in the larger scale tests (WP3 and WP4) planned in Phase 2 of the project, see Annex 1.

The tests are proposed to be conducted with (mainly) one fuel. The selection of this fuel is made from the results in WP1 combined with overall judgements of the interest in various fuel mixtures, depending on the total volumes handled and stored by the ethanol and oil industry.

The final test programme will, of course, need to be adjusted based on the results of WP1 and the results of each test in WP2 as it is run.

**Table 3. Work Package 2 - Laboratory Scale Tank Fire Tests.**

<b>Time schedule:</b>	M09-M21
<b>Objectives:</b> To plan and conduct a series of tests in laboratory scale, with one selected ethanol fuel and representing tank fire conditions, to evaluate the potential of various traditional and unconventional extinguishing medias and application techniques.	

**Description of work:**

The experimental work will be performed by SP in collaboration with RPI as needed to conduct the fire tests listed below. These proposed tests are subject to revision by the RT Group and the SC and may also be adjusted based on results obtained during testing. The tests will follow the same general setup as in WP1 except the tray will be deepened to simulate a small storage tank.

1. Backboard foam application close to the top of the “tank” wall
  2. Backboard foam application towards one side of the “tank” wall to achieve a swirling foam layer (“Swirl method”)
  3. Simulated foam chamber close to the top of “tank” wall
  4. Medium expansion foam using direct application
  5. CAF and backboard application (as in test 1, using a small scale CAF-generator with same flow rate as used in test 1)
  6. CAF distributed through an annular fixed system on top of tank wall.
  7. Selected additional test or retest with various application rates/methods
  8. Selected additional test or retest with various application rates/methods
  9. Selected additional test or retest with various application rates/methods
  10. Selected additional test or retest with various application rates/methods
  11. Alternative extinguishing technique - liquid nitrogen application (probably combined with subsequent foam application)
  12. Alternative extinguishing technique - foam glass application (probably combined with subsequent foam application)
  13. Selected additional test or retest with alternative extinguishing technique
  14. Selected additional test or retest with alternative extinguishing technique
  15. Selected additional test or retest with alternative extinguishing technique
- Some further tests could be valuable if funding/budget allow

**Deliverables:**

Technical report on findings of the laboratory scale tank fire tests summarising the indicated fire suppression capabilities for various extinguishing media and application techniques. The results and conclusions will be used as a basis for proposing the verification tests in Phase 2 (WP 3 and 4).

**3.4 Work Package 3: Medium Scale Tank Fire Tests**

The most promising extinguishing techniques from WP2 will be investigated in a medium scale (30 m<sup>2</sup> – 40 m<sup>2</sup>) tank setup in WP3. This work is part of Phase 2, therefore the details are not given here.

Please see additional information in Annex 1.

**3.5 Work Package 4: Large Scale Tank Fire Test**

WP4 involves a tank fire test in large/full scale. Whether WP4 can or should be realised will depend heavily on the evaluation of the results and experience from WP2 and WP3. This work is part of Phase 2, therefore the details are not given here.

Please see additional information in Annex 1.

### 3.6 Work Package 5: Heat Radiation and Burning Rate Tests

The intent of WP5 is to determine the burning behaviour of ethanol fuels under large scale conditions. During small scale conditions, the heat radiation and burning rate are less than those of gasoline but it is not clear whether this is true under large scale conditions. A gasoline flame will partly be blocked by soot particles, reducing the emissive power from the flame surface. As the flame from an ethanol fire is almost free from smoke, the reduction of the emissive power might be less in relative terms. This could imply that the heat radiation from an ethanol fuel fire will exceed that of a gasoline fire in larger scale fires, with the difference increasing as the scale increases.

There are several commercial computer programs for the calculation of heat exposure from pool fires and tank fires, but validation of large scale experimental data is lacking. This is also obvious as the calculated results might differ significantly between various programs depending on the assumptions made for ethanol fuels in the program code or by the user of the program. The intention of these tests is also to make accurate measurements of burning rate, flame height and heat radiation as a function of distance from the fire in at least three directions (upwind, downwind and crosswind).

Some pre-tests will be made in laboratory scale while the main work in WP5 will be focused on large scale conditions. The laboratory scale tests will be made to obtain some preliminary results on burning rate and to verify the measuring technique which will be used for the final planning of the large scale tests. The results will be valuable for understanding the influence of the scale factor on heat radiation and burning rate.

The results from these tests will generate extremely valuable data for accurate heat radiation calculations and improve the accuracy of risk assessments in fuel storage facilities.

**Table 4. Work Package 5 - Heat Radiation and Burning Rate Tests.**

<b>Time schedule:</b>	M0-M12
<b>Objectives:</b> To determine the burning behaviour of ethanol, primarily under large scale conditions, and to provide measurements for the validation of models of heat exposure from pool and tank fires. These measurements can also be used to improve the accuracy of risk assessments in fuel storage facilities.	
<b>Description of work:</b> The experimental work will be performed by SP in collaboration with RPI as needed to conduct the fire tests listed below. This list is subject to revision by the RT Group and the SC. Some pre-tests in laboratory scale will be conducted to provide input data for detailed planning and for evaluation of the measuring techniques. The main test programme will include 2-3 large scale pool fire tests with an area of about 250 m <sup>2</sup> (pool area about 18 m in diameter). The amount of fuel used in the tests will be based on the pre-tests (preliminary depth assumed to be 100 mm) but should be enough fuel to ensure a full intensity fire for at least 10 min. <ol style="list-style-type: none"><li>1. Pool fire, pre-test in a 1,73 m<sup>2</sup> tray using E97, measuring heat radiation, burning rate, weight loss, HRR, etc</li><li>2. Pool fire, pre-test in a 1,73 m<sup>2</sup> tray using E50, measuring heat radiation, burning rate, weight loss, HRR, etc</li><li>3. Pool fire of about 250 m<sup>2</sup> using E97</li><li>4. Pool fire of about 250 m<sup>2</sup> using E85</li><li>5. Pool fire of about 250 m<sup>2</sup> using E50</li></ol>	

- Some further tests in a “medium scale” pool (20-30 m<sup>2</sup>) could be valuable to provide an even better understanding of the scale factor if funding/budget allow.

**Deliverables:**

Technical report on the pre-tests and large scale tests, compilation of measurement data in a form that is useful for validation of radiation models and risk assessments.

**3.7 Work Package 6: Evaluation, Reporting and Dissemination**

Each work package will be reported separately in order to provide the basis for the detailed planning of subsequent work packages. These technical reports will give a detailed description of the test setup, test procedure and a full documentation of all test results. Both the internal dissemination within the Consortium and the external dissemination are further described in the ETANKFIRE Rules and ETANKFIRE Agreement

The project will also be reported in a final Phase 1 project report summarising the results and experience from the various WPs and providing tentative recommendations for one or several suitable fire fighting methodologies to be evaluated in medium (WP3) and large scale (WP4) in Phase 2.

The external dissemination of the project will also include presentation of results at various international conferences, in fire magazines, peer reviewed journals and on the SP website and/or other website(s).

There will also be a considerable number of photos and video recording from the tests and a selection of these will be made available on a DVD.

**Table 5. Work Package 6 – Evaluation, Reporting and Dissemination.**

<b>Time schedule:</b>	M6-M24
<p><b>Objectives:</b></p> <ul style="list-style-type: none"> <li>• Define a dissemination strategy that can maximise awareness about the objectives, status and outcomes of the ETANKFIRE project, both within the consortium and to external stakeholders.</li> <li>• Design, develop and regularly update the ETANKFIRE Website.</li> <li>• Guarantee the dissemination of project information and results through the Internet, publications, newsletters, printed matter, etc.</li> <li>• Develop a strategy for exploiting the ETANKFIRE results beyond Phase 1 of the Project.</li> </ul>	
<p><b>Description of work:</b></p> <p>A dissemination strategy will be put in place in order to maximise the dissemination of the ETANKFIRE objectives; each of the involved stakeholders (Full and Associate Consortium Partners and external stakeholders) will be addressed with the most appropriate tool and channel. Meaningful events and channels for presentations and diffusion of information about ETANKFIRE will be identified, assessed and selected.</p> <p>The ETANKFIRE Website will be regularly updated. It will consist of: a) a public part including description, prospects, news, events, publications, announcements and links to other relevant sites and b) a protected consortium related part including all intermediate results of the project (internal management/progress reports, deliverables, presentations, papers, public data sets, etc.).</p>	

**Deliverables**

Dissemination plan, project website, project leaflet, presentation of ETANKFIRE project in international conferences and/or trade shows, dissemination of technical reports for WP1, WP2, WP5, and the final technical report, and journal article(s).

**3.8 Location of the Tests in WP1, WP2 and WP5**

WP1 – WP2 are planned to be conducted in the large fire hall at SP Fire Technology. This will ensure the same test conditions throughout all tests.

The large scale tests in WP5 will require outdoor test areas in facilities capable of handling the proposed large scale pool fire. The test area should have a pool construction with a suitable diameter and without obstructions in the nearby area so that heat radiation measurements at various distances around the pool are possible. It is also important that permissions are given from relevant environmental protection authorities. One benefit of ethanol is that ethanol fires produce significantly less smoke than gasoline fires, while the tests with a high portion of gasoline will generate considerable amounts of smoke. A preliminary test area is the fire brigade training area in Borlänge in the middle part of Sweden.

**3.9 Estimated amount of fuel**

Below is an estimation of the total amount of fuel required to complete the proposed test programme in Phase 1 of the project.

- WP1: About 1 m<sup>3</sup> (various ethanol fuel mixtures)
- WP2: About 20 m<sup>3</sup>
- WP5: About 75 m<sup>3</sup>

**4 Project time plan**

Phase 1 of the ETANKFIRE project could be performed during a maximum time period of 2 years, given an agreed source of funding in advance of commencement. This would allow the various test series in each WP to be conducted in sequence, with evaluation of the test data timed to form the basis for the detailed planning of the following WP. As WP1 and WP2 are performed indoors, there are no restrictions from a weather point of view, while weather must be considered for WP5. This means that WP5 must have first priority for testing during the late spring – early autumn time of the year.

**Table 5. Project timing, beginning at project start up.**

WP	Description	Year 1					Year 2			
		3	6	9	12	15	18	21	24	
0	Project Management									
1	Literature Review									
1	Standard Scale Tests									
2	Laboratory Scale Tank Fire Tests									
5	Heat Radiation and Burning Rate Tests									
6	Evaluation, Reporting and Dissemination									

## 5 Budget and priorities

The work programme described above is based on a budget of about 500 k€, corresponding to at least 10 Full Partners. Some parts of the budget calculations are still uncertain, e.g., the costs for the fuel, fuel handling and destruction of the spent fuel, which might influence the figures. However, based on present estimates, the following budget applies to the various WPs.

**Table 6. Preliminary budget for Phase 1.**

WP	Activity	Approximate budget (k€)
WP 0	Management	35
WP 1	Literature review	12
	Standard scale tests	23
WP 2	Laboratory scale tank fire tests	160
WP 5	Free-burning tests	230
WP 6	Dissemination	56
	Total	516

As WP5 will be conducted outdoors, the tests need to be planned during a season where the probability for acceptable weather conditions is reasonable good, which is during the period late spring to early autumn in Sweden. As WP 5 also can be conducted independently of WP1 and WP2, it is proposed to prioritise the work in WP5 and conduct the full scale free-burning tests in Aug - Sept 2012.

The available budget for WP 5 is based on funding from the existing three Full Partners (SPBI, Brandforsk, Lantmännen Agroetanol, and a potential additional partner), all of which have expressed a particular interest in completing WP5 as the highest priority.

## 6 Revision history

Revisions that have been made to this document since the ETANKFIRE Description of Work has been formally established are listed in Table 1 below.

**Table 7. ETANKFIRE Consortium rules revision history.**

<b>Rev. No.</b>	<b>Date</b>	<b>Section</b>	<b>Description</b>
1			
2			
3			
4			

## **Annex 1 – Phase 2 Work Packages (WP3 & WP4)**

As Phase 2 of the ETANKFIRE project, aiming to conduct verifying tests in medium (WP3) and large scale (WP4), will require substantial resources, additional funding by participation of existing and perhaps also new partners, will be required.

A budget for these tests and the fee for participation will be decided when the work in Phase 1 is completed and fully evaluated of by the consortium members and a detailed test plan has been proposed.

However, to give an indication of the work possibly involved in Phase 2, below is a suggested preliminary content of WP 3 and WP4 based on our knowledge at present stage, before any tests in Phase 1 has been conducted.

### **Work Package 3: Medium Scale Tank Fire Tests**

The tests in WP3 will be performed in a medium scale tank setup with a preliminary fire area of about 30-40 m<sup>2</sup> (about 6 -7 m in diameter). The tests will only be made with those extinguishing techniques (2-3 alternatives) that were considered most promising in WP2. When using fire fighting foam, the increased fire size will require the use of commercial foam equipment and could represent real conditions for small storage tanks of corresponding size. Higher flow rates from a foam device will increase the momentum of the foam stream when landing on the fuel surface. This will, therefore, verify whether it is still possible to achieve a foam application that is gentle enough to allow the foam to survive on the fuel surface. It will also verify whether the application rates are relevant when the size of fire is increased.

The amount of fuel and the pre-burn time will be selected from the results in Phase 1.

The height of the tank needs to be considered, depending on the technique used, and two different tank heights might be needed. For handlines and monitor foam application techniques (backboard application), a small distance between the fuel surface and the top of the tank wall (high degree of filling) might cause the worse case conditions for gentle application, as part of the foam stream might hit the fuel surface directly. For a fixed over the top application system (foam chamber), or direct application of medium expansion foam or CAF, a large distance (low degree of filling) will increase the fall height and thereby the agitation of the fuel. The degree of filling might also influence the results for the alternative extinguishing media/methods. When using liquefied nitrogen, for example, the effect of wind might cause problems, especially at a high degree of filling.

Below are some examples of tests that could be foreseen, but it should be emphasised that the specific test series in this WP will be determined after the results of Phase 1 are available fully evaluated:

- Handlines and monitor using backboard technique (low clearance tank top-fuel)
- Handlines and monitor using backboard technique (retest, high clearance tank top-fuel)
- Medium expansion foam or CAF application (high clearance tank top-fuel)
- Test with a fixed foam application system (high clearance tank top-fuel)
- Test with alternative media/method (foam glass, liquid nitrogen, etc)
- Regarding the evaluation of fixed foam application systems, pre-tests (without fire) should preferably be made to study the foam distribution from various foam pouring

devices and the possibilities for the foam to flow gently along a tank wall. The tests should simulate a situation with a low degree of filling.

- For evaluation of the large scale performance of alternative techniques based on solid, heat resistant materials, e.g. foam glass spheres, the flow properties on a fuel surface will be very important. In order to evaluate this, and make comparisons with conventional foam flow properties, foam spreading tests on liquid surfaces should preferably be conducted. In total 5-6 tests could be considered realistic for WP3. If using alternative extinguishing media/methods evaluated in WP2, suitable application methods and equipment will also have to be arranged relevant for this scale and tested before a fire test is performed.

#### **Work Package 4: Large Scale Tank Fire Test**

WP4 involves a tank fire test in large/full scale. Whether WP4 can or should be realised will depend heavily on the evaluation of the results and experience from WP3.

The main goal of the test in WP4, should it be run, is to verify the most promising extinguishing technique from the tests in WP3 in real scale conditions. Considering economic and practical implications of tests at this scale, only a single test is expected and the size will still be limited compared to the largest existing storage tanks for ethanol.

The scale should at least be twice the size of WP3 and should, if possible, be conducted in a real storage tank. This corresponds to a tank diameter of about 12-15 m and a similar height, corresponding to a tank area of 100-175 m<sup>2</sup> and a volume of 1200-2600 m<sup>3</sup>. The degree of filling should be chosen to represent worst case conditions for the extinguishing technique identified as most promising in WP3, but a 25-50 % filling height is expected as a realistic estimate.