THE INTERNATIONAL ENERGY AGENCY HYDROGEN IMPLEMENTING AGREEMENT TASK ON HYDROGEN SAFETY

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Abstract

The International Energy Agency's Hydrogen Implementing Agreement (www.ieahia.org) initiated a collaborative task on hydrogen safety in 1994, and this has proved to an effective method of pooling expert knowledge to address the most significant problems associated with the barriers to the commercial adoption of hydrogen energy. Presently there are approximately 10 countries participating in the task and it has proven a valuable method of efficiently combining efforts and resources. The task is now in the fifth year of a six year term and will end in October 2010. This paper will describe the scope of the task, the progress made, and plans for future work. There are also a number of other tasks underway, and this paper will give a brief summary of those activities. Because of the nature of the International Energy Agency, which is an international agreement between governments, it is intended that such collaboration will complement other efforts to help build the technology base around which codes and standards can be developed. This paper describes the specific scope and work plan for the collaboration that has been developed to date.

1.0 INTRODUCTION

The lack of operating experience with hydrogen energy systems in consumer environments has been recognized as a significant barrier to the widespread adoption of these systems and the development of the required infrastructure. During recent years, a significant international effort has been initiated for the development of necessary codes and standards required for the introduction of these new systems. Such codes and standards are usually developed through operating experience in actual use that is accumulated over time. Without such long term experience, there is a natural tendency for such codes and standards to be unnecessarily restrictive to ensure that an acceptable level of safety is maintained. One possible effect is to hinder the introduction of hydrogen systems and this lack of operating data impacts other areas such as insurance cost and availability and public acceptance.

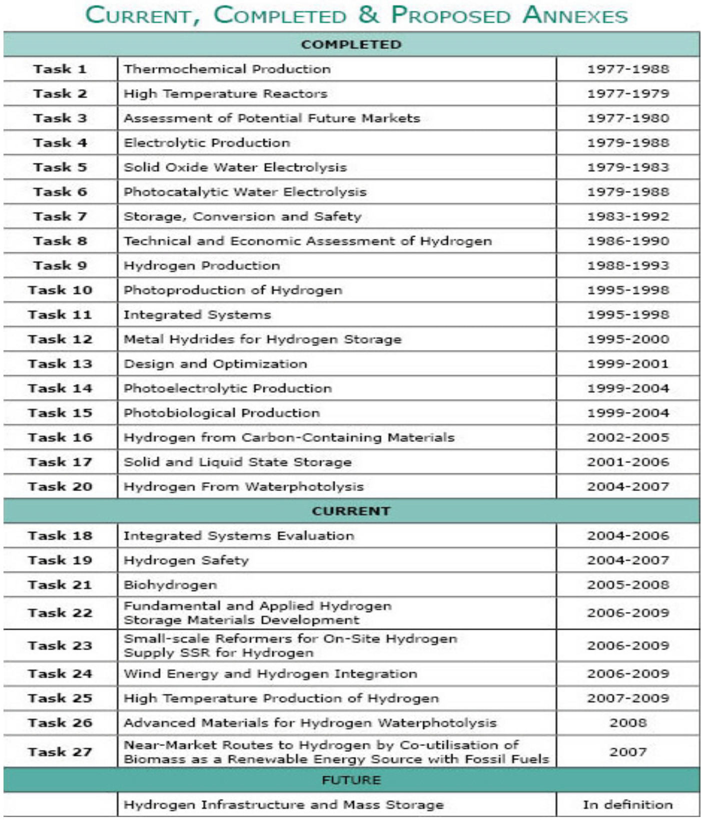
The overall goal of the new IEA task on hydrogen safety is to develop data and other information that will facilitate the accelerated adoption of hydrogen systems. A well coordinated and executed task on hydrogen safety will directly support the accomplishment of the Hydrogen Implementing Agreement's stated mission:

> *"…to accelerate hydrogen implementation and widespread utilization."*

Hydrogen has been commonly used in a number of applications for the last one hundred years. Much experience has been gained for its production and use as an industrial chemical and in space programs, where it has become the fuel of choice because of its high energy-to-weight ratio. An understanding of hydrogen's physical properties is well established, and many experimental efforts have attempted to fully characterize the risks and hazards related to hydrogen, but the actual risks and hazards can only be determined within the context of real systems and real operating experience. Because there is neither a large amount of operating experience nor a well-developed infrastructure for hydrogen energy systems, many of the evolving codes, standards or local regulations have the potential to become unnecessarily restrictive or burdensome to the would-be early adopters of the these new technologies and systems. As more experience and familiarity is gained with these new systems, many of the early restrictions may be eased and others may be strengthened. Real operating experience must include experience with the actual risks and hazards of new equipment and systems.

2.0 THE INTERNATIONAL ENERGY AGENCY'S HYDROGEN IMPLEMENTING AGREEMENT

The International Energy Agency Hydrogen Implementing Agreement was established in 1977 to pursue collaborative hydrogen research and development and information exchange among its member countries. Through the creation and conduct of 28 annexes, the HIA has facilitated and managed a comprehensive range of hydrogen R&D and analysis activities.



CURRENT, COMPLETED & PROPOSED ANNEXES

COMPLETED		
Task 1	Thermochemical Production	1977-1988
Task 2	High Temperature Reactors	1977-1979
Task 3	Assessment of Potential Future Markets	1977-1980
Task 4	Electrolytic Production	1979-1988
Task 5	Solid Oxide Water Electrolysis	1979-1983
Task 6	Photocatalytic Water Electrolysis	1979-1988
Task 7	Storage, Conversion and Safety	1983-1992
Task 8	Technical and Economic Assessment of Hydrogen	1986-1990
Task 9	Hydrogen Production	1988-1993
Task 10	Photoproduction of Hydrogen	1995-1998
Task 11	Integrated Systems	1995-1998
Task 12	Metal Hydrides for Hydrogen Storage	1995-2000
Task 13	Design and Optimization	1999-2001
Task 14	Photoelectrolytic Production	1999-2004
Task 15	Photobiological Production	1999-2004
Task 16	Hydrogen from Carbon-Containing Materials	2002-2005
Task 17	Solid and Liquid State Storage	2001-2006
Task 20	Hydrogen From Waterphotolysis	2004-2007
CURRENT		
Task 18	Integrated Systems Evaluation	2004-2006
Task 19	Hydrogen Safety	2004-2007
Task 21	Biohydrogen	2005-2008
Task 22	Fundamental and Applied Hydrogen Storage Materials Development	2006-2009
Task 23	Small-scale Reformers for On-Site Hydrogen Supply SSR for Hydrogen	2006-2009
Task 24	Wind Energy and Hydrogen Integration	2006-2009
Task 25	High Temperature Production of Hydrogen	2007-2009
Task 26	Advanced Materials for Hydrogen Waterphotolysis	2008
Task 27	Near-Market Routes to Hydrogen by Co-utilisation of Biomass as a Renewable Energy Source with Fossil Fuels	2007
FUTURE		
	Hydrogen Infrastructure and Mass Storage	In definition

Table 1. IEA Hydrogen implementing Agreement Tasks

This paper will discuss the current collaborative activities being conducted under Task 19, Hydrogen Safety.

3.0 DESCRIPTION OF THE HYDROGEN SAFETY COLLABORATIVE PROGRAM

Hydrogen Safety experts from 10 countries are currently participating in this task: Canada, France, Germany, Greece, Italy, Japan, The Netherlands, Norway, The United Kingdom, and The United States. The current collaboration was approved by the HIA Executive Committee in October 2004 and is currently in its second three-year phase that will continue through October 2010.

The specific objectives of the IEA Hydrogen Safety Task are to:

- develop testing methodologies around which collaborative testing programs can be conducted;
- collect information on the effects of component or system failures of hydrogen systems; and
- use the results obtained to develop targeted information packages for selected hydrogen energy stakeholder groups.

Three subtasks are being conducted under this subtask: 1)Risk Management, 2) Field Testing, and 3) Information Dissemination. They are described below.

3.1 Risk Management

Acceptability of new systems is traditionally measured against regulations, industry and company practices and the judgment of design and maintenance engineers. However, contemporary practice also incorporates systematic methods to balance risk measurement and risk criteria with costs. Management decisions are increasingly relying on Quantitative Risk Assessment (QRA) for managing the attainment of acceptable levels of safety, reliability and environmental protection in the most effective manner. QRA is being applied more frequently to individual projects and may be requested by regulators to assist in making acceptance and permitting decisions. It is a quantitative analysis methodology that can effectively fill in for the lack of operating experience for hydrogen systems in the pubic rather than industrial domain.

Subtask A Risk Management is concentrating during the second 3-year period on the following three activities:

- Develop uniform risk acceptance criteria and establish link with risk-informed codes & standards. Activity leaders: Jeff LaChance, SNL, USA and Angunn Engebo, DNV, Norway
- Develop a list of appropriate engineering models and modelling tools. Develop simple but realistic physical effects models for all typical accident phenomena (i.e., jet fires, vapour cloud explosions, flash fires, BLEVEs, pool fires, etc.) for education and training, design evaluation

and simplified quantitative risk analysis purposes. Activity leaders: Pierre Benard, HRI, Canada and Jay Keller, SNL, USA

- Develop methodology for consistent site risk assessment based on HyQRA approach. Activity leaders: Olav Hansen, GexCon, Norway, Koos Ham, TNO, Netherlands and Alessia Marangon, UNIPI, Italy

A relationship between the Activities and their contribution to quantitative risk assessment and risk-informed RCS process is illustrated by the Figure 1, below .

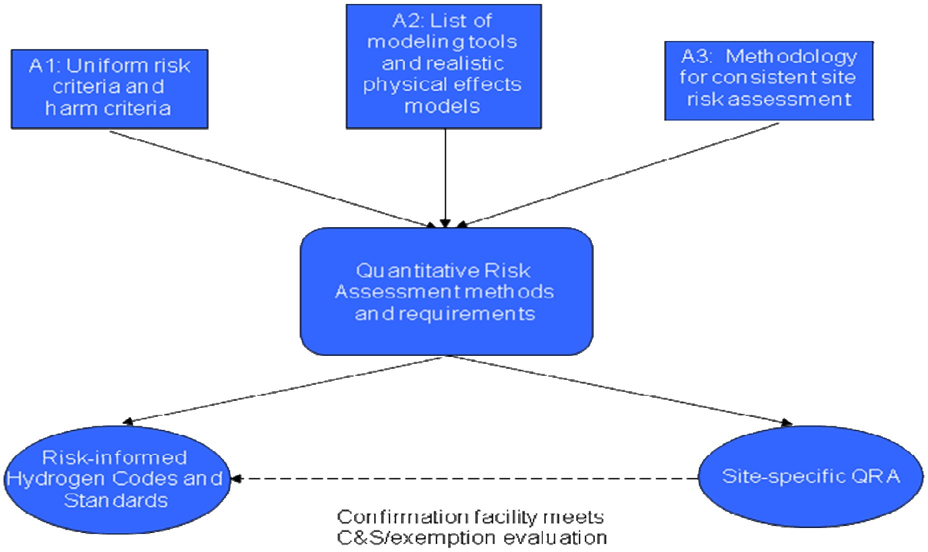


Figure 1. Relations ship between activities

3.1.1 Activity A1: Risk Acceptance Criteria and Risk-Informed RC&S

Risk acceptance criteria for societal risk, though de facto exist everywhere, are not always obvious. In some world jurisdictions, like in most Western European countries and Australia, they are incorporated into law. In the USA and Canada, to the contrary, as in many other jurisdictions around the world, they are not defined in any way and are, thus, subject to interpretation. It is quite obvious that if risk acceptance criteria, say, for the existing gasoline-dominated fuelling infrastructure are not known it is impossible to determine an acceptable level of risk for a hydrogen fuelling station.

This activity has the following objectives:

- Develop uniform risk acceptance criteria with regard to: types of risk measures, risk targets, and currently used risk criteria

- Recommend uniform risk acceptance criteria and provide rationale behind them
- Develop uniform consequence parameters or harm criteria for use in hydrogen QRA
- Develop a link to risk-informed codes and standards Risk and Safety Concepts

Ultimately, society determines what is considered to be safe based perception; safety is a societal construct, not an actual measure. Risk criteria are required to quantify risk, and most countries have the requirement that risk from hydrogen facilities should not substantially increase the risk from all other unintentional accidents that occur.

Other countries use the ALARP principle (As Low As Reasonably Practicable). It accepts the fact that there are no zero risk situations. The ALARP principle is that the residual risk should be as low as reasonably practicable and that the risk can be tolerated if additional risk reducing measures are either not feasible or their costs are larger than the benefit. Thus the tolerable level of risk is that which represents the level below which additional investment will not be made to reduce risk. In some versions of ALARP, there is no minimum risk to be achieved, but seeks continuous improvement in safety using best available technology. There is however a minimum risk level that must be obtained, regardless of cost, and this is referred to as the intolerable risk

There are a number of measures of risk such as human injury or fatality, economic loss, or environmental damage. There are also a number of identified risk targets which are used when assessing risk, e.g. members of the general public (people located outside the facility boundary, people living and working near the facility, or people that may be visiting or travelling near the facility), customers (people using the facility), facility operators (personnel involved in operation, inspection, and maintenance of the facility. It is usually assumed that facility operators accept higher risk levels than for customers and outside public

As part of the collaborative program, this activity is conducting a survey of *risk criteria* in general use where public risk measures are expressed in terms of fatalities. It was found that:

- Many countries use risk contours where no vulnerable objects are allowed within the contour, corresponding to a risk level (e.g., frequency of fatality = $1x10^{-6}$/yr).
- Some organizations suggest using the fraction of the total risk from all other unintentional injuries. Below are some of the results of the survey:
    - In the United States, the risk of death is approximately $2\text{-}4x10^{-4}$/yr and the risk of injury is ~ 0.09/yr.
    - The European Integrated Hydrogen Project (EIHP) has specified the value to be 1% of the average fatality death rate of $2x10^{-4}$/yr or 2x10-6/yr.

- The European Industrial Gas Association (EIGA) has suggested an individual risk value of $3.5x10^{-5}$/yr (~1/6 the average fatality risk).

- Fraction of total risk from just from fires ($1.3x10^{-5}$/yr in the U.S.) and explosions ($6x10^{-7}$/yr in the U.S.)

- For worker risk, the value used is ~ $1x10^{-4}$/yr for the European Integrated Hydrogen Project, and in the United Kingdom the value is ~$1x10^{-3}$/yr. for customers the value was ~ $1x10^{-4}$/yr

Uniform Risk Acceptance Criteria are also required for the development of risk-informed codes and standards, and there are several options for selecting risk criteria:

- Limited data from existing stations (gasoline and CNG) which may include accidents other than accidental releases. NFPA data for gasoline stations in U.S. suggest frequency of deaths and injuries per station are ~$1x10^{-5}$/yr and ~$3x10^{-4}$/yr, respectively.

- Limited analyses of estimated risk for existing stations, but differences in facilities affect comparison of data.

- Comparison with general risk in society, whereby hydrogen should not increase the general risk level in society,

Finally, *harm criteria* are required for the full range of accidents modelled in QRA.

- Jet fires, flash fires, pool fires, vapour cloud explosions (VCEs), Boiling Liquid Expanding Vapour Explosion (BLEVE), and detonations

- Thermal effects

- Specified heat flux level (static approach) – ranges in literature are used to define no injury, injuries (i.e., different levels of burns), fatalities, and damage to equipment and structures (concern about cascading failures)

- Thermal dose (dynamic, time-dependent approach) – discuss concept of thermal dose, identify dose ranges for different consequences, and identify available Probit functions

- Direct flame contact from fires –address duration of flame contact and resulting consequences

- Overpressure effects

- There is a range of peak overpressures cited in literature that result in personnel injury and structure damage. There are also Probit functions for overpressure-induced fatalities.

- Indirect effects – fragments or structural collapse
- Others, e.g., asphyxiation, cryogenic injuries, burning zone definition for flash fires

There are a number is key questions that must be addressed in developing uniform risk acceptance criteria:

- Should thermal dose criteria or radiation heat flux criteria be used, and what Probit functions should be used in thermal dose evaluation
- Selection of exposure time used in either method
- Should convective heat flux considerations be used?
- Include indirect effects in overpressure evaluation?
- Address asphyxiation and cryogenic effects?

3.1.2 Activity A2: Development of Realistic Physical Effects Models and List of Modelling Tools and Engineering Correlations

Selected physical effects modelling tools will be analyzed for accuracy and completeness, and updated. These tools will be used to develop realistic physical effects models for all types of accidents (i.e., jet fires, vapour cloud explosions, flash fires, BLEVEs, pool fires, etc.). The models are intended for education and training purposes of design engineers and regulatory officials, and also can be used as a guidance to identify risks from pre-defined component failure scenarios during a design stage and as well as for simplified risk analysis.

3.1.3 Activity A3: Methodology for Consistent Site Risk Assessment

Risk associated with unwanted hazardous events is a combination of two factors, the likelihood of the event and the seriousness of the event. There is a large accumulated body of knowledge on both the likelihood and severity of unwanted (accidental) events in conventional fuels such as gasoline, propane and natural gas (methane). The corresponding analyses for hydrogen have been highly dependent on the information and procedures for the latter conventional fuels. However, it is becoming increasingly apparent that dependency on data and models and modelling techniques derived from the conventional fuels can generate highly divergent evaluations of the behaviour of hydrogen upon release and the consequences.

This activity will be tightly related to Subtask B Testing Program which is aimed to provide data on component and system failure rates. In view of lack of experience with hydrogen systems in consumer environments, there is a corresponding lack of credible failure rate data for quantitative risk assessment. Both likelihood and consequence analyses as well as failure rate data for these systems use approaches that often lead to very conservative risk estimates, but they also show a strong sensitivity to modelling parameters and boundary conditions used when based on well-established conventional approaches. This emphasizes the need to base quantitative risk analyses for standardized hydrogen systems and consumer retail facilities on hydrogen-specific data and modelling techniques. This includes the real failure rate of key components installed in such systems with respect to their size and operating conditions as well as on scientifically and experimentally based data and methodologies for predicting consequences of failures of such key components.

This activity is based on HyQRA developed by Olav Hansen, GexCon, Norway for HySafe. The objective is to develop a reference Quantitative Risk Assessment (QRA) methodology for hydrogen technologies that ensures consistency in site risk assessments.

The tool supports the following steps:

- Hazard identification
- Frequency estimation
- Consequence assessments
- Risk estimation
- Validation of acceptance criteria for the application under consideration
- Assessment of measures for risk reduction

3.1.3.1 Methodology Development

There is a significant focus on regulations, codes, and standards (RCS) e.g. safety distance rules for handling hydrogen risk at the present time. CFD is used only occasionally, and mainly for worst-case evaluations. On the other hand, the validity of simplified methods, like venting guidelines, for hydrogen is unknown. Therefore, a comprehensive procedure for risk assessment of hydrogen applications, considering its most important objects, is needed and experiences from the oil and gas industry must be used. This includes relevant methodologies to define risk acceptance criteria, scenario and hazard identification including mechanisms of failure, frequency estimation, and consequence assessment and risk estimation as well as prediction of the risk effects for mitigation measures. Various levels of treatment, ranging from analyzing the worst-case scenario to a comprehensive study including ventilation, dispersion and explosion, to evaluate the probability for unacceptable events is considered. This is illustrated in Figure 2 that shows that the necessary precision level will vary with factors such as application, data/information availability and goal of individual risk assessment studies. The green line indicates worst-case screening; the blue line is the worst-case estimates with more accurate tools; and the pink line is the probabilistic approach.

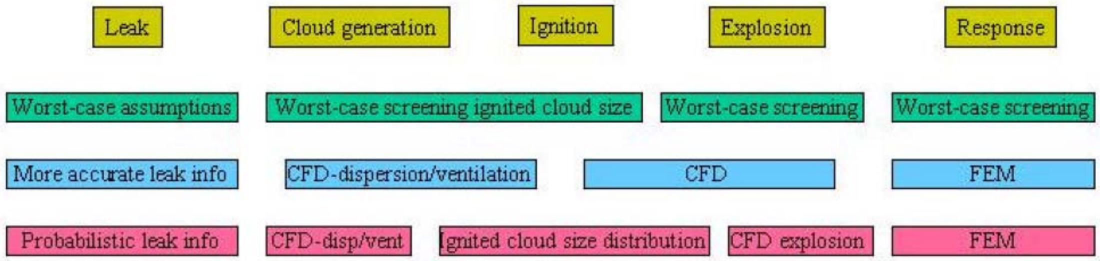


Figure 2. Illustration of levels of precision in risk assessment.

In QRA, the “worst-case” calculations are often unrealistic and predict unacceptable potential consequences. There are many advantages of a CFD-based probabilistic QRA including a good description of physics and dependencies, possibility to quantify a realistic risk level (slightly conservative where necessary), and transparent assumptions, which can be modified when more information is available. More simplified methods only use parts of the information available. For a realistic situation they are sometimes not applicable (due to limitations). If applicable, they may often be either non-conservative or far too conservative, and will usually not be able to predict the effect of a change or mitigation. However, they can still be valuable if applied properly as they can provide quick risk estimates. The applicability may improve with future developments (in progress within the HySafe project). Further, even CFD methods need to be simplified in order to achieve results in a reasonable length of time. It should always be made sure that these simplifications are realistic (and generally conservative).

It is hypothesized that if the method is constantly evaluated and improved, weak assumptions will lead to experiments and further studies, and gradually be improved with more experience and knowledge. The methods should be flexible allowing adjustments according to the requirements and needs of the different areas. Harmonization of the different partners’ methodologies will be a part of this development.

3.1.3.2 QRA Studies of Site-Specific Hydrogen Applications

The QRA methodology developed will be evaluated by comparison with available case studies of relevant H_2 applications using examples from HyApproval, automotive industry or elsewhere. These studies will also assess the effects of possible risk mitigation measures. The following activities can be envisioned for 2 different accident situations:

3.1.3.3 Failure Frequency Data Analysis

The goal of this activity is to identify approaches to establishing hydrogen leakage frequencies, phenomenological event probabilities and mitigating components failure probabilities. The collaboration is identifying approaches to establishing hydrogen leakage frequencies, phenomenological event probabilities and mitigating components failure probabilities as well as ignition probabilities based on available date and experience.

3.2 TESTING PROGRAM TO EVALUATE THE EFFECTS OF EQUIPMENT OR SYSTEM FAILURES UNDER A RANGE OF REAL LIFE SCENARIOS, ENVIRONMENTS AND MITIGATION MEASURES

For almost all risk analysis methodologies reference data is used for validating modelling and calculations of risk probabilities and/or consequences. With hydrogen being relatively new in large-scale use the question is if enough and proper validation data exists worldwide to perform calculations with the methodologies highlighted in Subtask A. The methodologies could point out the lack of data on hydrogen safety issues which makes it difficult to draw conclusions related to regulations (e.g. considering safety distances). Besides that, new applications and equipment have been suggested for hydrogen operating under more extreme conditions than applications and equipment used for conventional fuels. The safety features for these new applications and equipment should be tested and analyzed. This will also lead to new accidental scenarios addressed by Subtask A.

Subtask B will focus on both testing and experimental data, i.e., testing data as collected by checking the performance of applications and equipment and experimental data as collected by experiments with hydrogen release, ignition, fire, explosions and preventive and protective measures. o, testing data is more equipment specific, whereas experimental data is more hydrogen specific. Especially the experimental data could give new insight in controlling the size of hazardous areas. The smaller such an area, the less equipment will remain in a hazardous area resulting in less strict mitigating measures for the equipment.

The following activities comprise the current efforts of the testing program. This task will be completed during the final year of the current task period which end in October 2010.

Activity B.1: Survey on existing testing and experimental data

A survey will be carried out to collect testing and experimental data as much as possible. The data will be related to the specific application and/or equipment, use, testing conditions, testing methodologies, instrumentation, and so on.

Activity B.2: Survey on ongoing or planned test projects

A survey will be carried out to give an overview of ongoing or planned testing and experimental programs and projects. This will also include an overview of testing laboratories and facilities existing worldwide.

Activity B.3: Analyzing existing data in relation to risk management

In this activity the results of Subtask A will be linked to Subtask B. Lack of data arising from analyzing methodologies in Subtask A can be compared to the existing data. If data is not available this could give rise to new recommendations on testing and experimental programs, if yet not already covered by ongoing or planned testing projects. To a certain extent the data could also be checked on its relevance and completeness.

3.3 DEVELOPMENT OF TARGETED INFORMATION PACKAGES FOR STAKEHOLDER GROUPS

The development of a homogenous worldwide infrastructure will be necessary before hydrogen energy can achieve widespread utilization and public acceptance. Safety concerns caused by the lack of real operating experience (and the cost of their mitigation) are major inhibitors to the accelerated development of such infrastructure. As information is collected during the testing program, a beneficial impact can only be achieved if it is conveyed to those stakeholders who will participate in the development of the new infrastructure.

The goal of the information dissemination activity will be to use the results obtained in the testing and evaluation program to develop targeted information packages for stakeholder groups (permitting officials, insurance providers, system developers, the general public and early adopters of these new products and systems). This activity is more advanced in some countries compared to others that could benefit from the experiences gained in the infrastructure development process.

The specific information products will be developed during the last year of the collaboration

4.0 MORE INFORMATION

More information about the IEA and this task may be found by contacting the operating agent, William Hoagland at william@hoagland.us , or from the following web sites:

www.iea.org

www.ieahia.org

www.ieah2safety.com

5.0 REFERENCES

All references may be obtained at www.ieah2safety.com.

1. Task 19, Hydrogen Safety – Work Plan, October 15, 2007.

2. Task Annex, Hydrogen Safety, February 21, 2005.