U.S. DEPARTMENT OF ENERGY

PNNL-20082

Prepared for the U.S. Department of Energy
Under Contract DE-AC05-76RL01830

Safety Evaluation Report

Development of Improved Composite Pressure Vessels for Hydrogen Storage Lincoln Composites, Lincoln, NE May 25, 2010

WC Fort
EG Skolnik
RA Kallman
SC Weiner
MJ Maes

December 2010

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

This document was printed on recycled paper.
(9/2003)

PNNL-20082

Safety Evaluation Report

Development of Improved Composite Pressure Vessels for Hydrogen Storage

Lincoln Composites, Lincoln, NE May 25, 2010

WC Fort EG Skolnik
RA Kallman SC Weiner
MJ Maes

December 2010

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Lincoln Composites operates a facility for designing, testing, and manufacturing composite pressure vessels. Lincoln Composites also has a U.S. Department of Energy (DOE)-funded project to develop composite tanks for high-pressure hydrogen storage. The initial stage of this project involves testing the permeation of high-pressure hydrogen through polymer liners. The company recently moved and is constructing a dedicated research/testing laboratory at their new location. In the meantime, permeation tests are being performed in a corner of a large manufacturing facility.

The safety review team visited the Lincoln Composites site on May 25, 2010. The project team presented an overview of the company and project and took the safety review team on a tour of the facility. The safety review team saw the entire process of winding a carbon fiber/resin tank on a liner, installing the boss and valves, and curing and painting the tank. The review team also saw the new laboratory that is being built for the DOE project and the temporary arrangement for the hydrogen permeation tests.

Early in planning the program, the project team considered using 100% hydrogen to perform permeation tests. These tests study the degree to which alternative liner materials are permeable to hydrogen as a function of temperature and pressure. After consideration, management decided to use a mixture of 5% hydrogen and 95% nitrogen for testing in the building.

Engineering staff with general knowledge, experience, and association with the project work receive special training for testing with 5% hydrogen. When Lincoln Composites begins 100% hydrogen testing, the staff may also be sent to a hydrogen training course.

A project engineer developed and performed a Failure Modes and Effects Analysis (FMEA) to identify safety vulnerabilities.

Safety Review Team Recommendations

Based on the site visit, the safety review team recommends the following:

- The project team should construct a more robust barrier between the high-pressure cycling test area and the production floor. *(Recommendation 1, Section 3.1)*
- The project team should consider implementing and enforcing a personal protection equipment policy. This should include items such as safety glasses, dust masks, protective clothing and shoes, and related signage. *(Recommendation 2, Section 3.1)*
- The project team should confirm the hearing safety of employees. An industrial hygienist should be consulted to evaluate noise levels and the need for additional protection. *(Recommendation 3, Section 3.1)*
- If hydrofluoric acid (HF) is brought onsite, the project team should make an HF first-aid kit available. *(Recommendation 4, Section 3.2)*

- The project team should secure the hydrogen tubing in the permeation cell system to keep it from moving and either causing or propagating a failure. *(Recommendation 5, Section 3.3)*
- The project team should evaluate the need for personnel to wear flame-retardant clothing when working with solvents and resins. *(Recommendation 6, Section 3.3)*
- The project team should update their safety plan to reflect the current project work and use of hydrogen mixtures. *(Recommendation 7, Section 4.0)*
- The project team should complete an FMEA, with an appropriate set of experts involved in the review process. Hazard analyses are best performed by a team as opposed to an individual. *(Recommendation 8, Section 4.1)*
- The project team should determine whether the preventative maintenance database preserves maintenance records, including verification that a maintenance process has been completed, and if not, develop a procedure that will do so. *(Recommendation 9, Section 4.6)*

Acronyms and Abbreviations

DOE	U.S. Department of Energy
ECN	engineering change notice
EHS	environmental health and safety
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FMEA	Failure Modes and Effects Analysis
HDPE	high-density polyethylene
HF	hydrofluoric acid
ISV	identification of safety vulnerabilities
LMS	Lincoln material specification
MOC	management of change
MSDS	Material Safety Data Sheet
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PNNL	Pacific Northwest National Laboratory
PPE	personal protection equipment
SOP	standard operation procedure

Contents

Figures

1.0 Introduction

The U.S. Department of Energy's (DOE's) Fuel Cell Technologies Program gives paramount importance to safety in all aspects of its research, development, and demonstration projects. The Hydrogen Safety Panel helps the Program Office with integrating safety planning and practices into projects addressing production, storage, distribution, and use of hydrogen and related systems. Operated on behalf of DOE by the Pacific Northwest National Laboratory (PNNL), the panel conducts project safety reviews through site visits using an established protocol that emphasizes open discussion of safety practices and lessons learned. Working with the contractor's project team, a safety review team evaluates project safety practices and potential improvements and documents the results and recommendations in a report issued by PNNL to DOE.

Lincoln Composites operates a facility for designing, testing, and manufacturing composite pressure vessels. Lincoln Composites employs a staff of 125 and earns about $50M in annual sales. While most of the company's work involves natural gas vessels, the DOE project involves the development of composite vessels for hydrogen storage. Currently, Lincoln Composite's effort on the DOE project is limited to conducting small-scale permeation tests of liner materials at varying pressures and temperatures using a mixture of 5% hydrogen in nitrogen.

On May 25, 2010, the safety review team met with Dr. Norm Newhouse, Vice President of Technology; two of his project engineers; the manufacturing manager, who is also responsible for environmental health and safety (EHS); and another individual involved with EHS. The project team presented an overview of the company and project and discussed their safety planning and implementation methodologies using the safety review team's list of topic questions as an outline.

The five-member Lincoln Composites contingent also provided a tour of the facility, which is almost entirely a manufacturing and development facility for composite vessel work. The safety review team saw the entire process of winding a carbon fiber/resin tank on a liner, installing the boss and valves, and curing and painting the tank. The safety review team also saw the new laboratory being built for the DOE project and the temporary setup for the hydrogen permeation tests.

During the visit, the safety review team introduced Lincoln Composites to the Hydrogen Incident Reporting and Lessons Learned database, http://h2incidents.org, and Hydrogen Safety Best Practices, http://h2bestpractices.org, and presented two examples of incidents related to pressurized hydrogen systems.

2.0 Project Description

Lincoln Composites is developing carbon composite cylindrical vessels for vehicular compressed hydrogen storage. The vessels that Lincoln Composites manufactures are rated for ground storage to just under 15,000 psi. For this project, the vessels are only going to be filled to a maximum of 5,000 psi and are thus rated to 6,250 psi to meet the standard for a 25% safety margin. Vessels are tested at 7,500 psi.

The project team performs pressure cycling tests, burst tests, and drop tests. Other testing (such as bonfire tests) is contracted out to Powertech Labs. The safety of all contracted work is the contractor's responsibility.

The project has three phases, which are structured to achieve DOE's 2010 and 2015 hydrogen storage system goals by identifying appropriate materials and design approaches for the composite container. By the end of 2010, the project team hopes to have materials that can achieve a gravimetric capacity of greater than 6%, a volumetric capacity of greater than 0.045 kg H_2/L, and a storage system cost of less than \$133/kg H_2, based on the overall cost of the vessel divided by weight of the maximum hydrogen storage capacity.

Phase I (the current phase) aims to improve weight, volumetric efficiency, and cost performance, in part by improvements to design and materials. In Phase II, the most promising engineering concepts will be selected and their development continued to meet system requirements. In Phase III, subscale vessels will be fabricated and prototype systems will be assembled and evaluated. In addition, Lincoln Composites is considering development of composite vessels for containing metal hydride storage materials.

Phase I is focused on material identification for storage vessel components, including the resin-impregnated fiber vessel, the metallic boss, and the polymeric liner. The vessel liner must have low permeability to hydrogen.

The project team conducts small-scale permeation rate tests of liner materials by hydrogen at varying pressures and temperatures. Hydrogen is supplied via a cylinder containing a mixture of 5% hydrogen in nitrogen.

While planning the project, the project team considered testing at 100% hydrogen to perform permeation measurements. However, the project team's management decided instead to test with a mixture containing 5% hydrogen and 95% nitrogen. Lincoln Composites indicated that this decision was based on a lack of "feasibility of construction," and later added that "management decided not to create a 100% hydrogen facility; instead, tasks involving 100% hydrogen will be performed at outside laboratories."

Phase I also involves the development of the aluminum boss (the assembly for attaching valves and fittings to the end of the vessel). Lincoln uses an aluminum boss composed of a 7075 high-strength aluminum alloy. The boss is approximately 7 inches in diameter at its bond with the vessel.

The project team's goal is to reduce its safety factor from 2.25 to 2.0 times the maximum operating pressure, thereby reducing cost, and still achieve acceptable safety levels (i.e., damage vs. impact, stress capture). As part of this effort, the project team is evaluating non-destructive evaluation methods.

The project team is considering designing vessels for metal hydride storage, but it will be about four years before they begin developing this.

3.0 Facilities

In early 2010, Lincoln Composites moved its operations to a 108,000 sq ft. warehouse-style building that consists of two large production areas.

Lincoln Composites is constructing a laboratory to support the DOE project. A temporary work location has been set up in a corner of one of the production areas to accommodate the permeation activities until the laboratory is completed.

A bulk-storage area containing helium and nitrogen supplies is located outside the building. Helium is stored in a tube trailer. Nitrogen is stored as a liquid. The facility's liquid nitrogen capacity does not exceed 13,000 gallons and flows to a vaporizer at 77 K to make efficient use of the supply. Both of these gases have been used on the DOE project and will be used as well in the production of hydrogen pressure vessels.

As noted, the small permeation testing location is the only area used for the DOE project. However, since the safety review team toured the entire facility and saw the processes that will be used to construct hydrogen pressure vessels later in the project, a description of both the general production area and the specific project area is warranted.

3.1 Lincoln Composites Production Facility

The production facility is divided into two sections, one for the production of small vessels (9 to 21 inches in diameter and up to 10 feet in length) and the other for larger vessels (42 inches in diameter and 30 or 40 feet in length). The safety review team noted that the production floor is well maintained, clean, and unobstructed. Figure 3.1 shows part of the production area for the smaller diameter vessels.

Figure 3.1. Finished Cylinders Ready for Shipment.

Lincoln Composites has placed white boards throughout the production facility and encourages workers to write problems and questions on these boards. The safety review team commended this practice.

Process specifications are displayed in several areas of the facility. Each specification details the production processes for the area where it is displayed. A copy number on the specification cover allows the project team to account for each copy of a specification. More information on Lincoln Composites' specifications is provided in section 4.3, Standard Operating Procedures (SOP)/Process Documentation.

Material Safety Data Sheets (MSDS) are posted on facility walls, near the entrances.

The project team discussed the basic process steps for producing a composite high-pressure vessel:

- Raw materials such as high-density polyethylene (HDPE) are used for the liner. This polymer is attached to a metallic boss via a patented trap-lock arrangement. The boss material is generally aluminum, or a 3xx series stainless steel. The domes are injection molded HDPE and the cylinder is extruded HDPE. The domes and cylinders are joined with a butt weld joint using the hot plate method.
- Resin is applied to the carbon fiber or to a carbon/glass hybrid and the composite is wound onto the liner; three cylinders can be wound simultaneously. Lincoln often finishes the winding with glass fibers for surface abrasion resistance. Next, the vessels undergo a series of curing steps and then are proof-tested by being filled with water and pressurized to 1.5 times their service pressure. The proof-testing is performed in an enclosure constructed of rebar-reinforced concrete.
- The storage vessels are spray-painted in a paint booth and then placed into an infrared oven to cure the paint. Fumes vent to the outside. There is a fire suppression/sprinkler system inside the curing oven. (All ovens located in the facility have internal fire suppression.)
- After curing, a leak check is performed using helium or nitrogen at the vessel service pressure. Hydrostatic testing to failure is performed on 1 of every 200 vessels produced. Typically, a vessel will be cycled 10,000 to 15,000 times up to 1.25 times the service pressure.

The safety review team was concerned that the partial enclosure in which the recycling test took place was open to part of the general production area, and did not represent an adequate barrier.

Recommendation 1. The project team should construct a more robust barrier between the high-pressure cycling test area and the production floor.

Lincoln Composites: "Still needs [to be] addressed, but noted."

A burst test is also performed on a vessel to determine the ultimate strength of a cylinder design. Lincoln places a representative storage vessel in a metal tube, fills the vessel with water, and pressurizes the vessel to failure.

During the tour of the production facility, the safety review team noticed a man sanding excess cured resin off a vessel. He was not wearing any dust protection. The project team was not sure if this was a safety concern; however, Lincoln Composites plans to address the issue by installing automated vacuum sanders. These sanders will perform the same task of removing excess cured resin, but will do so without direct employee interaction. The safety review team also noticed some production workers were not wearing safety glasses.

Recommendation 2. The project team should consider implementing and enforcing a personal protection equipment (PPE) policy. This should include items such as safety glasses, dust masks, protective clothing and shoes, and related signage.

Lincoln Composites: "In place at this time."

Lincoln Composites employees receive ear plugs but are not required to wear them.

Recommendation 3. The project team should confirm the hearing safety of employees. An industrial hygienist should be consulted to evaluate noise levels and the need for additional protection.

Lincoln Composites: "Noted."

3.2 Hydrogen Testing Laboratory

The DOE project work will soon be housed in the new hydrogen testing laboratory, which is nearing completion. The laboratory consists of two rooms, a preparation/testing room and an instrument room, and is built into and partitioned off from a part of the production facility. When the laboratory is completed, a badge reader will limit access to trained personnel only. Laboratory materials will be tracked and an inventory log kept in each of the laboratory rooms.

At the time of this report, the laboratory has been completed and limited access via an electronic badge reader is in place. Figure 3.2 shows the instrument room.

Figure 3.2. Instrument Room, Hydrogen Testing Laboratory.

A small Instron apparatus for measuring mechanical properties of cured plastics and resins is already in place in the preparation/testing room. Dedicated acid and flammable materials cabinets are located under a hood in the instrument room.

The project team mentioned that boss-to-liner bonding tests will be conducted in the new laboratory. They may use dilute hydrofluoric acid (HF) for etching aluminum in this process. The safety review team was concerned about the corrosive and toxic nature of HF.

Recommendation 4. If hydrofluoric acid is brought onsite, the project team should acquire and make available an HF first-aid kit.

Lincoln Composites: "No HF is in the facility yet. If it is brought in it will be an etchant known as 'Keller's Reagent' which is a mixture containing 1.5% (vol) of 48% HF with 2.5% Nitric, 1% hydrochloric and 95% water. Concentrated (48%) HF will not be kept in the lab. Before Keller's Reagent is obtained, Calcium Gluconate HF Antidote Gel will be obtained in case of accidental contact with the skin."

3.2.1 Permeation Testing Temporary Work Area

Since Lincoln Composites moved to its new site in March 2010, the DOE project permeation testing has been conducted in a temporary work area while the new laboratory is being constructed.

Presently, the project team is using six permeation test cells. Figure 3.3 shows the hydrogen permeation testing at its current location. The permeation tests, which typically run at 5,000 psi and various temperatures, consist of pressurizing one side of an HDPE coupon and measuring the leak-through to the other side. The pressurized volume of each cell is approximately 4.5 cubic inches (74 cc). A mass spectrometer measures the hydrogen permeation rate.

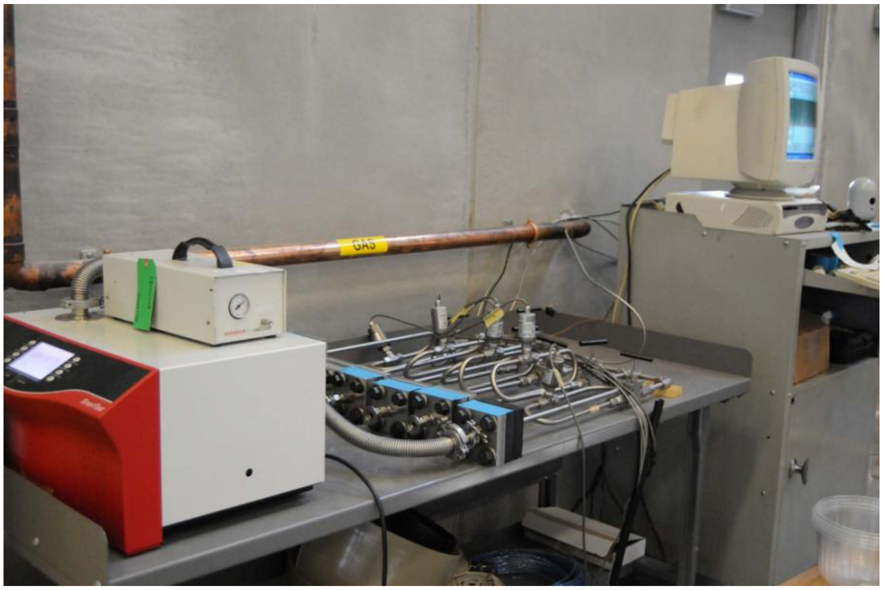

Figure 3.3. Permeation Testing at Temporary Location.

At the time of the site visit, samples had been in the cells for a month and a half. Because the permeability test cells are sealed, they do not need to be continuously connected to the 5% hydrogen cylinder. Thus, the cylinder was not stored in the test area. Storing compressed gas cylinders away from active locations is a good practice.

The safety review team noted that the permeation test apparatus, particularly the hydrogen-containing tubing, was not secured. This could result in a failure if the system were jarred, or the tubing could move uncontrollably if failure occurred for another reason.

Recommendation 5. The project team should secure the hydrogen tubing in the permeation cell system to keep it from moving and either causing or propagating a failure.

Lincoln Composites: "Yes, complete."

3.3 Materials Handling

Common pressure issues for compressed gases remain. With one exception, flammable gases are not used. The one exception is acetylene, which is used in welding in the facility maintenance area. Five percent hydrogen in nitrogen is not considered flammable. The only other gases used in the entire facility are nitrogen and helium.

Standard resin materials are used in the Lincoln Composites testing facility. Uncured resin can cause a rash if it contacts skin.

Solvents are stored within the Lincoln Composites testing sites, both inside the facility and outdoors. Acetone is used to clean equipment contaminated with resin. Two 55-gallon drums of acetone are stored in the building. The remaining acetone and any waste materials are stored in an outdoor storage shed.

Recommendation 6. The project team should evaluate the need for personnel to wear flame-retardant clothing when working with solvents and resins.

Lincoln Composites: "No action taken, but noted."

Lincoln Composites uses the Haz-Store system for waste storage. These standalone sheds store specific classes of hazardous materials and have safeguards to mitigate potential incidents related to the materials stored.

3.4 Hydrogen Supply/Handling

The project team stores their 5% hydrogen mixture in cylinder clusters; each cluster contains 12 Type K cylinders. There is no automatic shut down in the case of a leak, overpressurization, or loss of power or ventilation. The pressurization system for tests consists of a pneumatically powered gas pump that takes gas from the K bottles and increases the pressure to 10,000 psi. This system is manual. The operator monitors the pressure the entire time. As a safety feature, the pump pressure can be limited by limiting the shop air pressure, thus ensuring that the pressure vessel cannot be over pressurized.

As noted, the project team will not begin using 100% hydrogen until a later phase of the project. The project team is considering a walk-in fume hood for future 100% hydrogen gas use.

4.0 Project Safety

The project team's safety plan document was developed with the intent of using 100% hydrogen, but the plan was not finalized or approved after its review by the Hydrogen Safety Panel because of the decision to use a 5% hydrogen mixture. Lincoln Composites recognizes that a revised safety plan is needed—one that will address 5% hydrogen testing as well as testing, presumably using 100% hydrogen, possibly at larger volumes. At the time of this report, the safety plan is yet to be updated.

Recommendation 7. The project team should update their safety plan to reflect the current project work and use of hydrogen mixtures.

4.1 Identification of Safety Vulnerabilities (ISV)

Assessing the potential hazards of work at any scale begins with identifying an appropriate assessment technique. The ISV is the formal way to identify potential safety issues associated with laboratory or process steps, materials, equipment, operations, facilities, and personnel. The storage and handling of hazardous materials and related topics including possible ignition sources, explosion hazards, material interactions, possible leakage and accumulation, and detection are an integral part of ISV. For hydrogen handling systems, the source and supply, storage, and distribution systems, including volumes, pressures, and estimated use rates, need to be considered.

A project team design engineer prepared and conducted, on his own, a Failure Modes and Effects Analysis (FMEA) to identify safety vulnerabilities. In the future, he plans to use other Lincoln personnel for additional analyses such as addressing 100% hydrogen testing, and will consider involving outside participants.

Recommendation 8. The project team should complete an FMEA, with an appropriate set of experts involved in the review process. Hazard analyses are best performed by a team as opposed to an individual.

Lincoln Composites: "Concur – typically normal practice"

The project team's initial FMEA was based on the use of small amounts of hydrogen for the current ongoing permeation testing. The FMEA will be modified to include vessel testing before vessel testing work begins.

4.1.1 Scenarios Having the Greatest Risk

The project team indicated that there is no one worst-case scenario, but that a worst-case scenario would likely involve pressure, for instance, a composite vessel rupture from overpressurization. The mitigation plan for such scenarios include having burst tests on vessels built to the same design, non-destructive testing on each vessel and switches on the test equipment that prevent overpressurization. The project team mentioned asphyxiation as another potential worst-case scenario.

The project team also identified rashes from direct contact with the uncured resin as a less dangerous but more likely scenario. However, a resin rash has never been reported. The project team mentioned that there are PPE requirements at each work station.

The project team made a general statement that individuals learn from experience. This experience is much easier to gain on the production side, where activities become standard. With the DOE project work (or anything that is not standard production) there is more concern because personnel are not as familiar with the procedures. Thus, as the project team discussed, personnel, mainly engineering staff, are hand-picked for this project.

4.2 Risk Mitigation

It is important that prevention and mitigation measures be developed and implemented to reduce or eliminate the risks identified through an ISV analysis.

When Lincoln Composites reported that they used an FMEA to identify safety vulnerabilities, the safety review team speculated that the analysis may have revealed a failure scenario that influenced Lincoln Composites' decision to use 5% hydrogen rather than 100% hydrogen in the permeation tests. This was not the case, however; Lincoln Composites' management decision was not based on the FMEA.

Lincoln Composites has yet to implement a schedule to proceed with 100% hydrogen testing. They have, however, discussed the modifications needed before 100% hydrogen testing will be conducted:

1. Hydrogen supply and usage would be in an operating fume hood.
2. An electronic hydrogen sensor would be located in the fume hood. The testing at Lincoln Composites would consist of permeation of hydrogen tests in a pressure vessel, or with coupon specimens of liners. Risks of leaks or un-intended release of hydrogen would likely only occur during the act of pressurization or de-pressurization. These operations only occur under the supervision of qualified personnel. If the hydrogen alarm triggered at one of those times, the personnel present would shut down the process. If the alarm triggered at another time, while the vessel was under pressure, such as for the 500-hour permeation tests, there is nothing to shut down since hydrogen is not being transferred; only stored. Likewise, if the hood failed during a test, there is nothing to shut down.
3. Personnel working with the materials would receive detailed training.
4. Access to the hydrogen facility would be controlled.

4.3 Standard Operating Procedures (SOP)/Process Documentation

Procedures that describe the operating steps for the system, apparatus, equipment, etc., should reference specific safe work practices used to control hazards during operations, such as lockout, confined space entry, opening equipment or piping, and control over entrance into a facility. For SOPs, there should be clear understanding of who is responsible, where documents are kept, and how the documents are accessed by project, maintenance, contractor, laboratory, and other support personnel.

The project team stores 15 to 20 SOPs on a controlled server. Currently, there are no procedures addressing permeation, only production. Anyone can propose changes to a SOP, but such changes must be approved by all members of the Lincoln senior management team.

There is an SOP that discusses writing, gaining approval for, and releasing an engineering change notice (ECN). The ECN document explains changes for the staff. Other SOPs include Lincoln process specification and Lincoln material specification (LMS) documents. LMS documents are used for incoming materials inspection requirements.

4.4 Management of Change (MOC)

Any proposed change to materials, technology, equipment, procedures, personnel, or facility operation should be reviewed for its effect on the safety vulnerabilities of the work, including those at the frequently changing laboratory scale. Personnel should have a good understanding of the criteria used to initiate an organizational procedure for an MOC analysis and implement the results.

The project team would like to use an internal FMEA as a working document that can be changed as needed, but they are not yet at this point. Lincoln Composites will perform FMEAs that address changes such as new/different equipment, new processes, operating conditions, and procedures. The MOC also includes generating an ECN that states the change.

The project team is completing an FMEA for 5% hydrogen testing as an MOC procedure.

A safety review team member mentioned that there did not appear to be a formal MOC procedure. The safety review team was concerned that any change might not only need a requalification of the piece of equipment associated with the implemented change, but might also impact equipment downstream. An MOC procedure would identify the nature of that impact so that it could be mitigated. A sign-off on the MOC would also be a requirement.

4.5 Measuring/Monitoring of Safety Performance

Lincoln Composites performs safety inspections and holds audit discussions before any new equipment is brought into service. At the project level, a schedule ensures completion and review of training.

Quarterly reports are submitted for lost time and reportable incidents. Since 2006 the entire facility has not had any lost time or reportable incidents.

4.6 Equipment Maintenance

The integrity of equipment, piping, tubing, and other devices associated with any hazardous material handling systems is an important safety consideration.

The project team documents information on equipment maintenance, calibration, testing, and instrumentation in the equipment's LMS.

Personnel need to be internally certified before they can operate equipment.

All maintenance documents are kept in a preventative maintenance database that alerts staff when calibration is needed. The database is located on Lincoln Composite's server. The safety review team thought that the database could have additional uses, such as keeping records of previous maintenance and providing verification that a scheduled maintenance process was completed. The project team was unsure whether the database had those capabilities.

Recommendation 9. The project team should determine whether the preventative maintenance database preserves maintenance records, including verification that a maintenance process has been completed, and if not, develop a procedure that will do so.

Lincoln Composites: "Yes, current system has this ability and is utilized."

4.7 Training

Formal programs and planned hazard-specific training related to the hazards of any project are important to ensuring the safe conduct of work. Any organization needs to steward training participation and verify understanding to confirm the value of the training program.

Lincoln Composites requires general production line training for all production personnel. The engineering staff leads the training. New personnel must attend Emergency Planning and Community Right-to-Know Act (EPCRA) training and complete a hazardous waste training module. Lincoln Composites also provides annual refresher training for its employees. This is both general production line training and EPCRA training.

Lincoln Composites originally planned to use a special training protocol for 100% hydrogen use. This has been tabled until the project needs to start using 100% hydrogen at which point engineering staff with general knowledge, experience, and association with the project work will receive special on-site training for working with hydrogen. Personnel may also be sent to an off-site hydrogen training course. (See further discussion in Section 8.0.)

4.8 Emergency Response

Emergency response procedures should be in place and a part of regular communication to and training of employees. Communication and interaction with neighboring occupancies and local emergency response officials is an important aspect.

Lincoln Composites addresses emergency evacuation in an SOP. Employees are instructed to call 911 and not to try to put out a fire themselves. Evacuation plans and a map are also posted in the laboratory.

The local fire department conducts an annual inspection of the Lincoln Composites facility. Lincoln Composites provides a list of hazardous substances that are used at their facility to the fire department, which is within a mile of the facility. The fire department is also notified when the list changes. The project team involved the local fire department in safety planning decisions for the new building.

Fire alarm pull boxes are located near offices. The fire department confirmed that current pull boxes are adequate and that no additional pull boxes are required. There are also thermal sensors in the building that activate both audible alarms and the sprinkler system.

Tornado and fire safety drills are held annually. Every year or two Lincoln Composites executes a "burn out" (hand-held fire extinguisher training) in the parking lot, involving production and office personnel as well as first responders.

5.0 Communications

5.1 Safety Meetings

A monthly meeting is held to specifically discuss safety, training, and hazardous materials incidents during the prior month. The meeting format is a review of injuries, prevention of potential injury, and a basic review of safety concerns. These safety meetings are general in nature, not specific to this project. Safety discussion is also included discussed at weekly staff meetings.

5.2 Safety Events

A near miss form (Figure 5.1) is completed if there is an incident without injury and also if there is a potential injury that results from an incident. Lincoln Composite's EHS coordinator is responsible for notifying DOE if there is an incident.

LINCOLN

NEAR MISS – INCIDENT INVESTIGATION FORM

Incident Information	
Incident Date:	
Employee Name:	

Explain the incident in detail:

Who?	
What?	
Where?	
When?	
How?	

What injury or potential injury resulted from the incident?

What was the cause of the incident?

Action Necessary

What action will be taken to prevent this incident/injury from re-occurring? (State if there is immediate action necessary vs. long-term action necessary.)

Date to be completed:		Who is responsible for the action?	

Signatures

Name of Investigator:		Date:	
Dept. Head Signature:		Date	
EHS Manager Signature:		Date:	

Verification Of Action Completion

Dept. Head Signature		Date:	
EHS Manager Signature:		Date:	

Copies to: EHS Manager, HR Manager, Controller, President

Figure 5.1. Near Miss Incident Investigation Form.

6.0 Regulations, Codes, and Standards

The project team complies with normal product specifications. They participate in the development of and comply with the following vessel standards – CNG: NGV2, H2: HGCV, Forklifts: HPIT1, and CSA B51 Part 2, CNG: ISO11439, H2: IS015869, Transportable: ISO11119 and TC197.

For pressure testing, the project team follows the guidelines from National Fire Protection Association (NFPA) 52, NGV4, and/or NGV3. The project team does not participate in NFPA standards development, but they do follow NFPA guidelines.

The project team also works with Occupational Safety and Health Administration (OSHA) and U.S. Environmental Protection Agency (EPA) standards to monitor effluents (paint fumes) exiting the building.

No special permits are needed at this time.

7.0 Lessons Learned (by the Project Team)

Lincoln Composites noted the importance of having a team of people involved in safety planning who can provide fresh opinions. People often think they can work more efficiently alone, but the project team feels that this is not the best philosophy. For example, at the start of this project, one design engineer worked alone to conduct the project's FMEA for identifying safety vulnerabilities. Future plans call for an FMEA to be performed by a team.

During the report writing process, Lincoln Composites presented an example of a team effort involving an outside expert: "We recently held a 'five S' (lean manufacturing) event in our winding and leak cell areas. We brought in an outside contractor from the University of Nebraska, Omaha, to facilitate this event. During this event they were able to bring in new ideas and safety related practices that other manufacturing sites have found useful to help them with workplace organization. This gives a fresh look at potential safety hazards and how to avoid them."

8.0 Questions from Lincoln Composites

- The project team asked whether it is acceptable to have a 55-gallon drum of acetone on the floor of the main work areas. To enhance facility safety, the review team suggests that the project team store flammable and combustible liquids in approved cabinets or storage rooms. Liquids outside of approved storage should be limited to quantities necessary for a 24-hour period, and in no case should the amount exceed the fire code maximum allowable quantity. Additionally, liquids handled above their flash points should be transferred in closed systems or at locations having adequate exhaust ventilation and ignition source controls (including unclassified electrical equipment and elimination of electrostatic sources, open flames, etc.). NFPA 30, Flammable and Combustible Liquids Code, and the International Fire Code can provide additional details on approved containers and transfer methods.

- The project team requested information on hydrogen safety training, specifically for developing their 100% hydrogen training program. The safety review team recommended the links to training programs found at http://www.hydrogenandfuelcellsafety.info/resourcesTraining.asp as well as the now-available online training tool developed by Lawrence Livermore National Laboratory, found at http://www.h2labsafety.org.

Appendix A

Attendees at the Lincoln Composites Site Safety Review

Appendix A

Attendees at the Lincoln Composites Site Safety Review

Project Team

Name	Title/Affiliation
John Barnhard	Manufacturing Manager, Lincoln Composites
Jon Knudsen	Project Engineer, Lincoln Composites
William Lackey	EHS/Industrial Manager, Lincoln Composites
John Makinson	Sr. Design Engineer, Lincoln Composites
Norm Newhouse	Vice President Technology, Lincoln Composites

Safety Review Team

Bill Fort, Consultant, Hydrogen Safety Panel
Richard Kallman, City of Santa Fe Springs, CA; Chair, Hydrogen Safety Panel
Miguel Maes, NASA-WSTF, Propellants and Materials Program Manager
Ed Skolnik, Energetics Incorporated, Panel Technical Support, Team Leader

Pacific Northwest
NATIONAL LABORATORY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnl.gov

U.S. DEPARTMENT OF
ENERGY