Hydrogen has potential applications that require larger-scale storage, use, and handling systems than currently are employed in emerging-market fuel cell applications. There has been extensive work evaluating regulations, codes, and standards (RCS) for the emerging fuel cell market, such as the infrastructure required to support fuel cell electric vehicles. However, there has not been a similar RCS evaluation and development process for these larger systems. This paper presents an evaluation of the existing RCS in the United States for large-scale systems and identifies potential RCS gaps. The paper also identifies areas of potential safety research that would need to be conducted to fill the RCS gaps.

This analysis supports the H2@Scale project work.
NFPA 2 National Hydrogen Code

194 Pages of Hydrogen safety

Adopted in Most US jurisdictions

- Referenced in the 2015 International Fire Code
- Referenced in NFPA 1 Uniform Fire Code
- These two Fire codes are used in almost every jurisdiction in the US
- Federal facilities often invoke compliance with NFPA requirements
- Covers almost all aspects of hydrogen safety

NFPA 2 provides the base for hydrogen technologies including large systems

RCS for Large-Scale Renewable Hydrogen Generation

Chapter 13 of NFPA 2 has fairly limited requirements for production

<table>
<thead>
<tr>
<th>RCS Document</th>
<th>Subject Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFPA 3 Hydrogen Technology Code</td>
<td>Chapter 13 hydrogen production</td>
</tr>
<tr>
<td>NFPA 3 13.2.4 Staging</td>
<td>Structural requirements, exclusion from electrical classification zone, and safe venting (or Chapter 6)</td>
</tr>
<tr>
<td>NFPA 2 13.3.1 Indoor Installation</td>
<td>Perimeter for indoor venting</td>
</tr>
<tr>
<td>NFPA 2 13.3.3.1 Indoor installation</td>
<td>setback distances for installations below and above the maximum allowable pressure</td>
</tr>
<tr>
<td>NFPA 10 National Electrical Code</td>
<td>Electrical requirements for classified areas</td>
</tr>
<tr>
<td>CGA H-5.5</td>
<td>Vent stack design including vent termination geometry</td>
</tr>
<tr>
<td>ASME B31.3 (3 and 12)</td>
<td>Pipe design for hydrogen piping systems (including dimensions and materials)</td>
</tr>
<tr>
<td>CGA-H1, 1-1.3</td>
<td>Pressure relief device design</td>
</tr>
</tbody>
</table>

RCS FOR LARGE-SCALE HYDROGEN STORAGE SYSTEMS

Current Requirements

- NFPA 2 addresses bulk gaseous storage in unlimited amounts and bulk liquid storage up to 283,906 L (75,000 gallons)
- Systems that are larger than current employed by industry may be considered to be outside of the scope of the prescriptive requirements in NFPA 2 Hydrogen Technologies Code
- NFPA 2 give performance-based option

Excerpt from NFPA 2 bulk liquid storage table

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Diameter (in.)</th>
<th>Volume (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>30</td>
<td>10,000</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
<td>25,000</td>
</tr>
<tr>
<td>250</td>
<td>50</td>
<td>50,000</td>
</tr>
<tr>
<td>300</td>
<td>60</td>
<td>75,000</td>
</tr>
</tbody>
</table>

RCS HYDROGEN TRANSPORT: PIPELINES, RAIL, AND HIGHWAY

Pipeline network is very limited in the US to certain geographic areas

<table>
<thead>
<tr>
<th>Transport Method</th>
<th>RCS Document</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen pipelines - hydrogen is conveyed under pressure of the part of the U.S. Department of Transportation (DOT) regulations as a flammable gas</td>
<td>DOT 49 CFR Part 192 Subparts A-P and 735</td>
</tr>
<tr>
<td>Temperature control, piping, and process control</td>
<td>DOT 49 CFR Part 192 (Revisions 715 and 716)</td>
</tr>
<tr>
<td>Rail transport</td>
<td>DOT 48 CFR Part 192</td>
</tr>
</tbody>
</table>

Table 2. RCS for hydrogen transport
Example installation: performance based approach to large-scale production and storage installation

The basic parameters:

- Wind turbines capable of generating megawatts of power
- Electrolyzers capable of producing (combined with liquefaction plant) 5,360 kg/day (20,000 gallons/day)
- Storage system capable of holding 26,800 kg (100,000 gallons) of liquid hydrogen
- Transport capable of moving 5,360 kg/day (20,000 gallons/day)
- Based on fuelling > 1000 vehicles or supplying a small network of stations

Key Elements of Performance Based Approach

- Very broad open-ended approach with qualitative compliance targets
- Will require data collection to evaluate hazards
- Will require a significant effort to demonstrate compliance
- Will require working closely with enforcing authority
- May be the only way to get large unique systems approved

Research Required to Deploy Large Systems

- Component performance in large scale storage systems is yet to be demonstrated for some components
- Electrolyzer oxygen/hydrogen mixtures may present a flammability hazard and require more detailed requirements in NFPA 2
- Performance based compliance for systems outside of current boundaries is an area that will require further work
- Communications for system to perform in an integrated fashion may require further work
- Hydrogen Wide Area Monitoring (HyWAM) to detect releases in large storage systems is a technology that needs to be developed and demonstrated
CONCLUSION

• Large scale systems not defined in RCS
• Portions of large scale systems may fall outside of the boundaries of current RCS
• Approval process for these systems may require a performance based approach similar to that applied to large LNG storage systems
• No US national system of hydrogen pipelines- filling this gap will require additional safety analyses
• Research may be required in characterizing risk and safety measures for large scale systems

Thank You and Questions

• Carl Rivkin, CSP, P.E. - Safety Research Team Lead
carl.rivkin@nrel.gov

This work is supported by the DOE EERE Fuel Cell Technology Office!