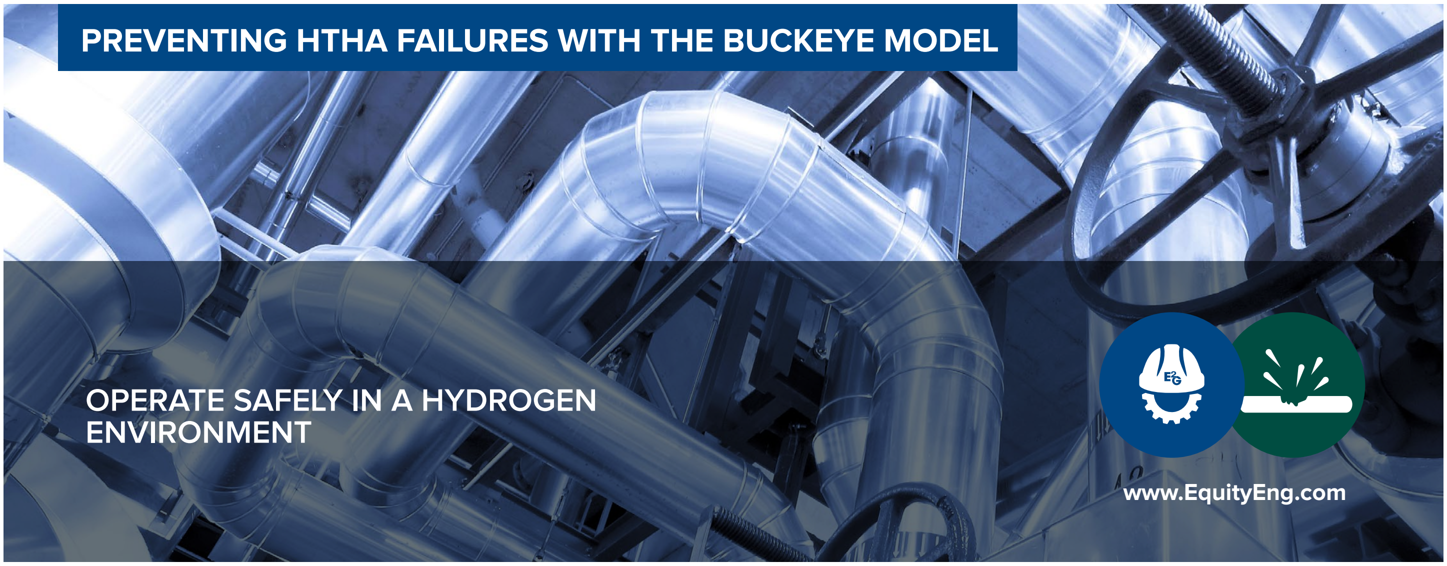
# PREVENTING HTHA FAILURES WITH THE BUCKEYE MODEL

## OPERATE SAFELY IN A HYDROGEN ENVIRONMENT




## HTHA DAMAGE

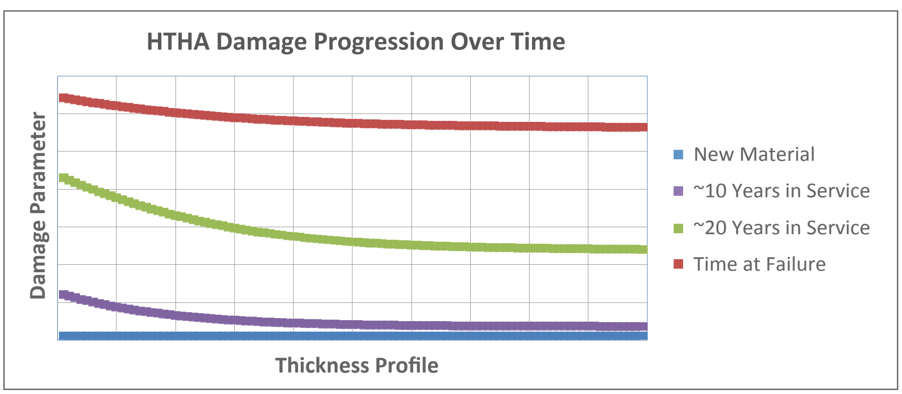
High Temperature Hydrogen Attack (HTHA) is the progressive degradation of carbon and low alloy steels exposed to hydrogen at elevated temperatures. Accurately predicting HTHA failures has proven to be one of the most elusive problems challenging the industry for more than half a century. Although basic guidelines for choosing ostensibly safe combinations of temperature and hydrogen partial pressure are provided in API RP 941, there continue to be unexpected failures. This prompted the development of a more sophisticated approach for the prediction of HTHA remaining life.

## E²G HTHA JOINT INDUSTRY PROJECT

In 2013, E²G initiated an ongoing Joint Industry Project (JIP) to focus on three essential tasks necessary to better understand HTHA life prediction:

- Develop a predictive model of HTHA damage progression and ultimate failure.
- Evaluate and improve the ability of current NDE methods to detect existing HTHA damage.
- Perform additional testing in hydrogen environments to further improve failure predictions.

**This effort has led to the most powerful tool for HTHA life prediction to date – the E²G Buckeye Model.**




Damage prediction of a carbon steel heat exchanger operating at ~750°F at ~200 psia hydrogen

## PREDICTIONS YOU CAN TRUST

The true test of any model is how well it predicts real world failures. Well documented data on HTHA failures is limited; however, the Buckeye Model has been shown to be consistent with reliable failure data from API RP 941 and other sources.

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## THE E²G BUCKEYE MODEL

E²G's Buckeye Model integrates the primary physical mechanisms known to be responsible for HTHA damage: diffusion of hydrogen through metal; thermodynamics and kinetics of methane formation; growth of methane-filled voids by creep of the surrounding material; and the increased tendency for cracks to initiate and grow. By integrating these mechanisms into one cohesive model, E²G has developed the first truly comprehensive and practical method of HTHA damage prediction.

The most important aspect of the model is that it accounts for the time-dependent nature of HTHA. The Nelson Curves in API RP 941 do not account for this time dependence. Additionally, the model accounts for other important factors such as:

- Variable operating conditions
- Type and thickness of material (base metal and cladding)
- Heat treatment (PWHT vs. non-PWHT)
- Welding residual stress
- HTHA crack-like flaws analysis
- Existing damage (including localized damage)

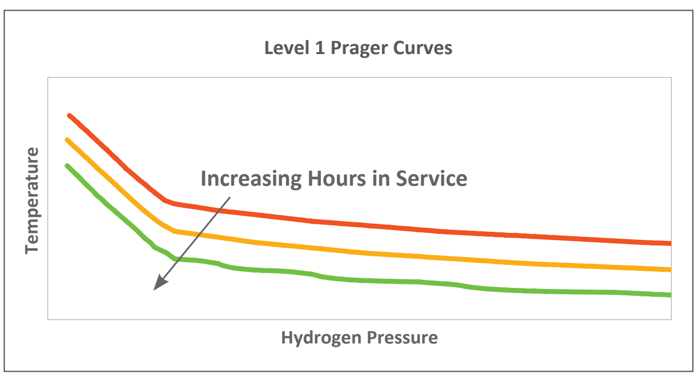
## NEW FITNESS FOR SERVICE PROCEDURES

The Buckeye Model forms the basis for a new set of Fitness-for-Service (FFS) rules that have been delivered as part of the JIP work conducted by E²G. The remaining life is predicted separately for two modes of failure:

1. Volumetric failure when the distributed damage (void density) reaches a critical level.
2. Crack growth failure when the assessment point lies outside of the FAD (Failure Assessment Diagram).

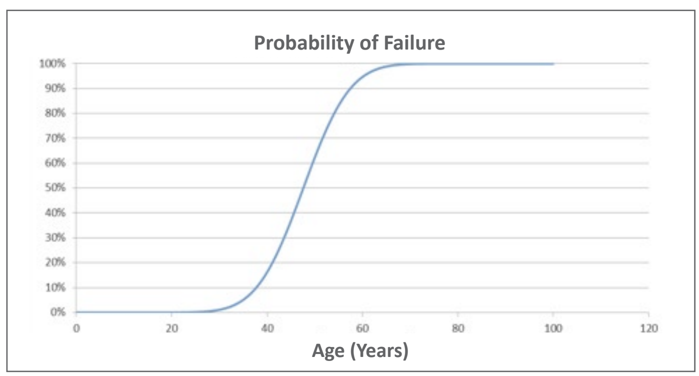
As with most FFS procedures, increasing levels of sophistication are employed. A Level 1 FFS assessment uses a set of graphical screening curves that resemble the traditional Nelson curves except they also account for the time-dependence of HTHA. These time-dependent curves are named the Prager Curves in honor of Dr. Martin Prager (Director of The Welding Research Council, Inc.), the originator of this approach and a close collaborator with E²G on the HTHA JIP project.

## TIME-DEPENDENT PRAGER CURVES




Failing a Level 1 FFS assessment is not the end of the story. Instead, a more sophisticated Level 2 FFS can be performed by running the Buckeye Model for HTHA assessment.

## EMBRACING UNCERTAINTY




Our experts at E²G assess components using the Buckeye Model. Detailed information for equipment operating in HTHA environments is often limited. Statistical methods are used to characterize uncertainty, and probabilistic models are used to estimate the probability of failure over time.

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